AUSTRALIAN BUILDING PRACTICE

JAMES NANGLE, O.B.E.

J.M. Ross
Engineering I.
1945

AUSTRALIAN BUILDING PRACTICE

A Treatise for Australian Students of Building Construction, Builders, Architects, etc.

By

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With Numerous Illustrations by the Author

Fourth Edition – Revised and Enlarged

WILLIAM BROOKS & CO., LIMITED

SYDNEY

1944

REGISTERED AT THE GENERAL POST
OFFICE, SYDNEY, FOR TRANSMISSION
THROUGH THE POST AS A BOOK

PREFACE TO FIRST EDITION

The matter contained in the following pages was originally prepared in the form of notes for instruction to students in the Building Construction Class formerly under the Author's charge at the Newtown Technical School. The notes were afterwards amplified and re-written in the form of articles for publication in the pages of the "Building, Engineering and Mining Journal," from which they have been reprinted in the present form.

The Author is not aware of the existence of any work devoted to the description of the materials and methods of Australian building construction. He, therefore, hopes that this little book, even though he cannot but feel that it has many shortcomings, will be found to be of some use, not only to students, but also to Architects and Builders.

The Author has endeavoured to acknowledge in the text the sources of the information which he has used. He, however, wishes to especially acknowledge his indebtedness to Professor Warren, of the Sydney University, and Mr. J. H. Maiden, Government Botanist of New South Wales, from whose published works much valuable information has been obtained. He is, also, greatly indebted to Mr. R. T. Baker, Curator, and Mr. G. H. Smith, Assistant Curator, of the Technological Museum, at Sydney, who have been at all times ready to give information about the specimens in the invaluable Institution under their charge. He is very grateful to these gentlemen, and also to the many of his friends who by advice and suggestions have helped in the preparation of these articles.

Sydney,
August, 1900.

PREFACE TO SECOND EDITION

The first edition of this book having been for some time exhausted, another is now offered to the student. It will be found that the original edition is much revised and that several chapters have been added. The results of a large number of tests of materials, made under the Author's supervision at the Sydney Technological College, are also included.

The very kindly way in which the original edition was received, in spite of its many defects, encourages the Author to hope that this one will also be favourably received.

The Author gratefully acknowledges much help received from Professor W. H. Warren, Wh., Sc., M.I.C.E.; Messrs. R. T. Baker, F.L.S.; H. G. Smith, F.C.S.; J. C. H. Mingaye, F.C.S., F.I.C.; Hugh Wright, N. Nurzey, J. Farrell, E. Cambridge, and A. H. Martin, and from his son Norman. To all these and the many others who have helped, he is very thankful.

Sydney,
17th Feb., 1911.

PREFACE TO THIRD EDITION

Fourteen years have elapsed since the publication of the second edition of this book. A great part of the period was much disturbed by the great war. Nevertheless, it has been characterised by great activity in building construction in all parts of Australia. Speaking generally, it can be said that there has been a steady advance in design and execution. Owing to various causes, materials, especially timbers, formerly barely known beyond the pages of this book, are now extensively used. Most of the Australian States are rich in materials of the highest quality, and it is believed that the previous editions of this book have helped to make these materials known and have assisted towards the skilful use of them. It is the earnest hope of the Author that this edition may also help in the same way.

The Author thankfully acknowledges help received from many Engineers, Architects and Builders, and especially the help received from Mr. George Edwards in assisting with the reading of the proofs.

Sydney,
10th Nov., 1925.

PREFACE TO FOURTH EDITION

Nineteen years have elapsed since the publication of the third edition of this book, and it is now three years since my father died. It was his intention that he, together with my brother Alan and I, completely review this book, and both my brother, who is away on active service, and I have revised this book as he wished that it should be done.

Since the last edition there have been some changes in construction, especially in construction design, and many new materials have been made available.

It is hoped that this new edition will prove as useful as the previous editions in making the materials known, and also in helping towards the use of them.

The writer thankfully acknowledges the help received from his wife in the reading of the proofs, and is grateful for the care taken and attention given by the publishers to this new edition.

JOHN E. T. NANGLE, A.R.I.B.A., A.R.A.I.A.
Director, Nangle Institute of Technology

Sydney,
14th Feb., 1944.

CONTENTS

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CONTENTS—*Continued*

CHAPTER XIII

CHAPTER XIV

CHAPTER XV

CHAPTER XVI

CHAPTER XVII

CHAPTER XVIII

Index to Tables

LIST OF ILLUSTRATIONS

[1] From Johnson's "Materials of Construction"

LIST OF ILLUSTRATIONS—*Continued*

1 From Examination Papers, Sydney Technical College
2 Students' Copy Drawing, Sydney Technical College

1 From Messrs. Dorman Long & Co.'s Catalogue
2 From "Architectural Engineering"
3 From "Architectural Iron and Steel"

1 From "Expanded Metal Co.'s Catalogue"

AUSTRALIAN BUILDING PRACTICE

CHAPTER I

FOUNDATIONS

1. Examination of Building Site. The examination of the building site is very important, for the safety of all that may be erected thereupon depends on the knowledge possessed concerning the material forming the site, and the judgment and wisdom displayed in the arrangement of the foundation. The builder will need not to seek far for examples of heart-breaking failures, due to faulty foundations; and, indeed, long is the list of engineering and building troubles, presented as a warning, that unless care is exercised, difficulties in this direction are very likely to occur. It is therefore at the start absolutely necessary to ascertain the nature of the material forming the site on which the building is to stand, and, not only that, but the surrounding conditions likely to interfere with the material are also to be investigated and allowed for. In districts where the character of the underlying material is well known, and where building has been carried on for a long time, experience will have established ample data to work upon, when arranging for the foundation of an ordinary building; but, should the building be of an extraordinary weight, even in such places special examination is advised. On the other hand, in new districts, with nothing to guide in the way of experience, such as is often the case in Australia, the builder must perforce make an examination.

2. Method of Examination. The most satisfactory method is to sink bores, or deep perpendicular holes, at intervals over the site. By this means a full knowledge of the character and arrangement of the materials comprising the site will be obtained, and any expense incurred this way will be amply counterbalanced by the removal of all risk to the building arising from ignorance of the building site.

3. Classification of Natural Foundations. The materials forming building sites may be divided into four classes as follows:—

(1) Unyielding.
(2) Unyielding except under certain conditions, such as sand, and gravel, when subject to the action of water.

(3) Yielding, as, for instance, soft clay, silt, and swampy or marshy ground.

(4) Partly yielding.

Class I.—Unyielding Natural Foundations

4. Solid Rock. The deep and solid rock formations are to be placed under the head of unyielding or incompressible natural foundations, and, of course, offer the best possible conditions for building upon, requiring nothing more than levelling off the inequalities to receive the footings of the building. It is not usual to put on the rock more than one-tenth of its ultimate crushing strength.

5. Rock in Boulder Formation. If, however, the rock is not of a solid and compact nature, the case is altogether altered, for often a comparatively sound stratum of rock will be found deficient in thickness, and underlain by a more or less rotten seam, incapable of bearing weight. Again the rock sometimes occurs in the shape of large blocks or boulders, with a soft or decomposed material surrounding them and filling the interstices. This description of rock is a most treacherous kind of foundation, on account of the probability of settlement or dislocation of the boulders, which may be brought about either by the inability of the soft material to bear increase of weight, or by its being removed through the action of subterranean water. In the case of a heavy building it will be necessary to excavate through such a formation to a solid stratum.

6. Hard Shale. Hard shale makes an excellent foundation, provided it is not subjected to atmospheric influence, for on exposure it rapidly disintegrates, and is reduced to a powder. In the event of the shale being naturally exposed, care should be taken to have the portion supporting the footings of the building sufficiently covered with earth, stone, or other covering.

7. Hard Clay. Hard, dry, compact clay is practically unyielding, and is a good, safe foundation, especially if intermixed with gravel, but the footings of the building should be carried down sufficiently far into it, for the upper part of the clay to a depth of five or six feet is liable to severe changes, due to atmospheric influence. Expansion and contraction occur to such a degree that buildings resting on the upper portion of the clay may be cracked, distorted, and rendered unsafe. In some of the districts subject to drought, cracks from 1½in. to 2in. wide appear during the dry period. It is usual in buildings of no great weight, where cost prevents very deep

sinking, to lay a bed of sand about 4 or 6 inches thick, in the trenches before the laying of the footings, so that any movement due to expansion or contraction is prevented, by the cushion afforded by the sand, from affecting the building.

8. Clay on Side of a Hill. Where a clay foundation occurs on a side of a hill, it will be necessary to inspect that portion of the slope below the proposed building. Should cuttings or drains exist, allowance is to be made for probable slipping of the clay caused by the falling in of the sides of the cuttings or drains. Accidents to buildings have happened where the cutting has been a considerable distance below, and with a view of providing against such a failure the footings must be very much deeper than in the case of a flat site.

Class II.—Unyielding Except Under Certain Conditions

9. A Compact Sand Gravel is unyielding when protected from the action of water, and makes a very good foundation. **Loose Gravel** may be prepared for bearing the weight of the building by being saturated or grouted with thin cement grout.

10. Dry Sand is one of the best weight-resisting materials for a foundation, but sand is rendered quite useless by the presence of water. All sand, unless it is laterally confined, spreads when subject to weight. Where the surface is level for some distance round the buildings, and also free from effects of flood or other water, sand will be found to answer well; but on the side of a hill, or in any place where it can slip or spread out, or where subjected to the action of running water, the portion under the building should be confined or retained by sheet piling. When piles are driven close together in a line the arrangement is called "sheet piling," and is the method adopted to confine sand and other loose materials. The piles are driven between guide piles and longitudinal pieces called "waling pieces." The foot of each pile is cut or bevelled, as indicated by Fig. 1, with a long and short bevel, and is placed as is also shown in Fig. 1, so that during the driving process a tendency towards the last driven pile is caused. By this means the piles are brought close together. The "sheet piling" can only be used as a temporary measure. If the material is to be confined permanently, a retaining wall of brick, masonry, or concrete should be constructed.

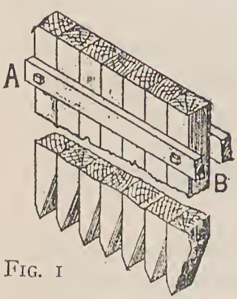


Fig. 1

Class III.—Yielding Natural Foundations

11. Ordinary Clay is capable of bearing a very fair weight without serious compression; but, as in the case of the hard clay before mentioned, it will be necessary to excavate to a depth free from the effects of weather change.

12. Soft and Porous Clays. Pure soft or porous clays and soft, loamy earths form the medium class under the heading of yielding materials, for, though not as good as ordinary dry clay and solid, hard earth, they are very much better than quicksand or mud. The method of dealing with these materials is, however, much the same as for silt, quicksand, and mud; the only difference in their favour being that, should access to a better substratum be impossible, it will generally be feasible to spread the weight to a safe load by using wide footings, whereas in a swampy or silty ground the use of piles is almost unavoidable.

13. Silt, Mud, and Quicksand. Silt, quicksand, and swampy soils are the most unreliable and treacherous materials that can be met with for building upon. Unfortunately, such materials often occur, because in cities convenience requires that large stores and manufactories should be erected along, or as near as possible to, river frontages or harbour shores, and it is in such places that mud and silt are most likely to be found. The weight-bearing power of these semi-fluid deposits is very small, and is very much of the same character as that afforded by water when supporting a floating body. However, as bad as may be the foundation afforded, examples are offered where heavy buildings have been safely founded on quicksand, or mud deposits, but safety has only been provided for by very skilful spreading of the weight on footings with a large area.

Class IV.—Sites Composed of Unyielding and Yielding Materials

14. So far only cases of sites composed wholly of **unyielding, unyielding except under certain conditions,** and **yielding,** have been dealt with; but it frequently occurs that one part of the site is unyielding and the other yielding, such as a water frontage which may have silt and mud of considerable depth over a great portion of the end near the water, and the remaining part may be solid rock. To erect a building partly on unyielding and partly on yielding beds would be sure to produce disaster, because it must be remembered that **it is not so necessary that the bed on which the building rests shall be**

unyielding as that it shall be absolutely uniform in its weight-bearing power. It will be therefore most important that the softer materials be excavated, and all the footings founded on material of the same character. If the drop or fall to the strongest material be very great, the part of the building over the soft portions of the site may be supported on piers reaching to the level of the hard material.

15. Determination of Weight-bearing Power of Natural Foundations—Footings and Improvement of Yielding Foundations. With the unyielding natural foundations there will be no difficulty whatever in the matter of arranging the area of the lower parts of the footings, because, unless the imposed building be of a most extraordinary weight, the bearing power of this class of foundations is rarely ever reached. The various precautions, noted during their description, need only be taken. It is in foundations of the yielding class that difficulties are met, and to overcome them requires the exercise of the greatest skill and care. Such foundations being compressible in a more or less degree, it will be necessary to determine the safe load for the particular kind of formation.

16. Estimation of Bearing Power. The following formula from Rankine's "Civil Engineering" will serve to determine the depth that must be sunk into, and safe pressure that may be put upon, quicksand, soft clays, and alluvial soils:—

W = weight of a unit volume of the soil, quicksand, or clay.
h = depth to which the footings are to be sunk.
A = the angle of repose of the soil, quicksand, or clay.

then $Wh\left(\frac{1 - \sin A}{1 + \sin A}\right)^2$ per unit of area.

An application of the above is as follows:—

W = 100lbs. per cubic ft. for soil.
h = 5ft. as depth of footings into the soil.
A = say 15°.

Consult a table of sines for sine 15°. It will be found to be ·25882.

then $100\text{ft.} \times 5\text{ft.} \left(\frac{1 - \cdot 25882}{1 + \cdot 25882}\right)^2 = 100 \times 5\text{ft.} \times 2{\cdot}9.$
$= 1450$lbs. pressure per sq. ft.

17. Angle of Repose. The angle of repose is the inclination of the slope at which the materials will naturally settle. It

can be very easily determined by making a heap, sufficiently large, of the particular material, and measuring the inclination of the slope or batter of the heap.

18. Advantage of Deep Excavations for Footings. It will be seen from an inspection of the formula that the depth to which the footings are sunk is a consideration, and this will be evident, for the silt (or mud) being in a semi-fluid state its tendency is to spread immediately on the imposition of a load, but such spreading is not so likely to occur when the load is applied at a level at some depth into it, because the silt under the load is kept in its place by the lateral resistance of the surrounding silt. Therefore the greater the depth, the greater will be the weight of that surrounding. Again, the angle of repose is also a factor, because the greater the angle the less will be the tendency to spread, and hence clay will have a greater supporting power than quicksand.

The table here given will be found of value when designing the bearing area of footings.

TABLE I

Showing Safe Bearing Power of Materials usually met with for building upon.

Material	Remarks	Safe Bearing Power in Tons per sq. ft.
Rock		One tenth of the crushing strength.
Gravel . . .	Compact and sound in deep strata.	8
Gravel . . .	Fairly loose.	3
Sand	Compact and free from water and not liable to slip.	6
Sand	Ordinary but free from water and not liable to slip.	4
Shale or Clay .	Dry, and in deep strata, hard.	4
Clay	Fairly dry and hard.	1.5
Clay	Ordinary, but liable to be wet.	1
Alluvial and earthy or poor clayey soils . .		.5

19. Design of Footings. Having determined the safe pressure per square foot, the next step will be to make the bottoms of the footings of area sufficiently large to transmit the load so as not to exceed such safe pressure. An example will, perhaps, more fully explain what it is intended to convey by the foregoing:—

A pier, together with the load on it, weighs 10 tons.
The materials of which the building site is composed will safely bear, say, 2 tons per square foot.

$$\left.\frac{10 \text{ weight of pier and load on it}}{2 \text{ tons safe load per sq. foot}}\right\} = 5$$

So that the area of the footing of the pier should be 5 sq. ft.

To find the area of footing required under a long wall, it is only necessary to take one lineal foot of the wall and treat same as for a pier.

Of course, the total weight of the building must be accurately arrived at, and also the exact amount thereof borne by the lower parts of the various walls and piers, so that the area of the footings may be proportionate. A pier in the same building as the one in the above example, with a load (including its own weight) of 6 tons, to be in proportion, its footing area should be 3 sq. ft.

Suppose, for instance, it were otherwise, and that it had footing of the same area as the pier with 10 ton load, the soil would be unequally loaded, and unequal settlement would take place, and cracks occur in the building as a consequence. It will therefore be evident that, as well as having a uniformly weight-resisting natural foundation, it is also **just as necessary to provide for all footings being in proportion to the weight borne.** Settlement is not so much to be feared, as that one portion shall settle more than another.

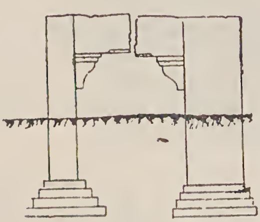


Fig. 2

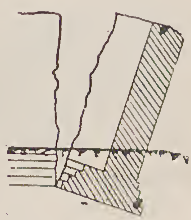


Fig. 3

20. Proportion of Footings. Fig. 2 illustrates a mode of failure, where the areas of the footings are not properly proportioned.

21. Centre of Pressure. The centre of pressure of the wall or pier should be over the centre of bearing of the footing area. Fig. 3 shows a failure owing to the wall being built on one side of the footing.

22. Concrete Footings. For footings the best method to adopt is to lay a bed of concrete in the trench. The area of the bottom of the concrete to be proportioned to distribute the load safely, and the thickness to be great enough to prevent transverse breaking. Concrete is spoken of as being the best in such cases, because, not only is it very strong in itself, but, if properly laid, the whole bed becomes one mass, or piece, and consequently distributes better than stone or brickwork. (See article 77 hereinafter for Composition of Concrete.)

23. Spreading Courses. The portion of the wall next above the concrete should be spread out in "**stepping**" or "**offset**" courses to provide for the proper distribution of the weight over the concrete. (See Fig. 4, which indicates the proper

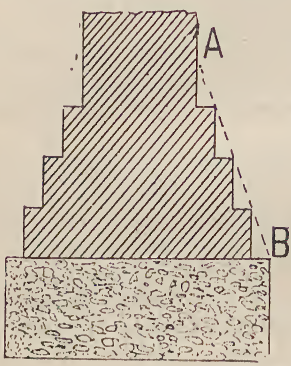


Fig. 4

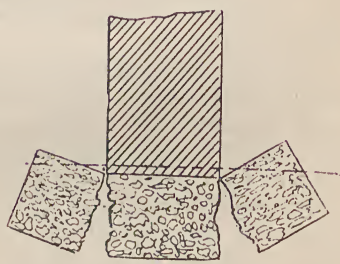


Fig. 5

method.) The greater the inclination made by the line AB, the more stable will be the work, and the inclination of AB will be increased as the projection of each offset is lessened. Fig. 5 shows a wall built without offset courses on the concrete, together with the mode of probable failure.

24. Masonry or Brick Footings. When for various reasons, such as cost, etc., it is found impossible to use concrete, the footings may be of masonry, or brick-in-cement, but the same precaution as to spreading, noted in last article, must be taken. However, masonry or brick footings are never as efficient as concrete, for it is not possible to obtain the same compactness and homogeneity throughout the whole mass.

25. Iron Hoop in Brick-in-Cement Footings. The value of brick-in-cement for footings is greatly enhanced if lengths of galvanized iron hoop of stout gauge be built in between the courses.

26. Steel Rail or Beam Footings. Architectural engineers have developed a method of securing a very large amount of bearing area, with a very small thickness of footing. By reference to Fig. 4, and remarks already made concerning the inclination of AB, it will be evident that, with concrete or masonry footings, the greater the area, the greater will be the number of offset or spread courses, and consequently the greater the height or thickness of the footings. At Chicago, U.S.A., perhaps more than at other places, has the question of building foundation been fully considered, and with the unusual conditions existing, it is not surprising that the matter has had extraordinary attention. With such tall building, and a natural foundation of very small weight-bearing power, necessity arose for either footings of great area or piles. The serious disadvantages connected with the driving of piles (to be touched on hereafter) caused a tendency to use footings, but the massive and clumsy system of spreading masonry, or concrete, was departed from, and the necessary stiffness and strength gained with a comparatively small thickness, by

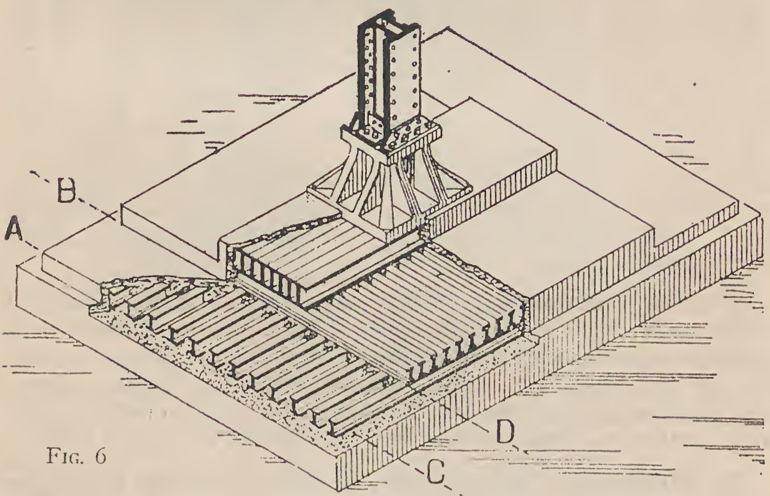


Fig. 6

using steel rails, or I beams, arranged as shown by Fig. 6. The lower layer of beams rests on a bed of concrete, and the spaces between the beams are filled up with concrete. The beams should be well coated with cement grout paint, prior

to laying. The sketch, Fig. 6, shows the arrangement of a steel beam foundation for supporting a steel column with cast-iron base. The design of such footings against failure is governed by precisely the same conditions as in the case of masonry or brickwork offset courses, and the projection of each layer beyond the one next above must be considered as a cantilever uniformly loaded by the reaction of the pressure due to the portion of the load which it distributes. If not properly designed, each projecting layer would break as would the badly-proportioned footing shown by Fig. 5. The bottom layer may be taken as an example. Let the load of the column, together with the weight of the upper layers, be 1,056,000 lbs., and the area of the lowest layer 16 ft. x 22 ft. = 352 square feet. Then 1,056,000 lbs. ÷ 352 square feet = 3,000 lbs., which would be the pressure per square foot, exerted by the lower layer on the clay. The lower layer projects 4 ft. on each side of the layer next above, hence the area of each projection is 16 ft. x 4 ft. = 64 square feet. It will therefore be clear that, of the total pressure exerted by the bottom layer, the projections thereof take each 192,000 lbs. The projection of the lower layer marked ABCD in Fig. 6 would therefore be calculated as a cantilever with uniformly distributed load of 192,000 lbs. pushing upwards and tending to break it along the line BD. The method of finding the bending moment of such a cantilever will be explained under the heading of girder design. Each of the layers must be taken in the same manner, with the column load and the weight of the layers, or layer above (the top layer will have only the weight of the column load), and the reaction found for each projection. It is, of course, to be noted that the intensity of pressure or weight per square foot **increases** as the area of layer **decreases,** so that the top layer will exert greater pressure per square foot than will the lowest layer. Steel beam footings may be used with advantage on all compressible soils.

27. Pile Foundations. With soft clay or mud soils and quicksands, it very often happens that it is not practically possible to obtain sufficient footing area to spread the weight, and in such cases it becomes necessary to resort to piles. Bearing piles, as they are called, are long pieces of timber (generally circular in cross section) driven vertically into the soil.

28. Method of Driving Piles. Piles are usually driven by blows from a falling weight called a "**ram**" or "**monkey.**" Fig. 7 shows the general form of the machine by which the ram is raised and let fall on the head of the pile. After each fall, the ram is raised, either by hand-power applied to a crab winch at the feet of the "**leaders,**" or by steam-power, and when raised

to a sufficient height a sudden release from the perpendicular rope is effected by means of the claw lever shown in the sketch. The two upright pieces which guide the ram in its descent are called "leaders," and the ram itself is usually a block of cast-iron. As will be seen by Fig. 7, the ram is provided with a tongue or projecting piece E, which fits between the "leaders," while the plate B, bolted to the tongue, prevents the ram from getting away as it descends. The height of the fall of the ram in these machines may be anything up to, but (for reasons to be given hereafter) should not be more than 30 feet. The weight of the ram varies from 500 up to 3,500 lbs. Experience has served to show that a light ram with a high fall has a greater tendency to compress and split a pile than a heavy ram with a low fall. Again, with a heavy ram and low fall, the blows may be delivered very rapidly, and this is an important matter, for it has been observed that if a pile be driven to a certain depth, and allowed to remain for some time undisturbed, and be then again struck with the same ram with same fall the penetration will not be as great. This is explained as follows:—

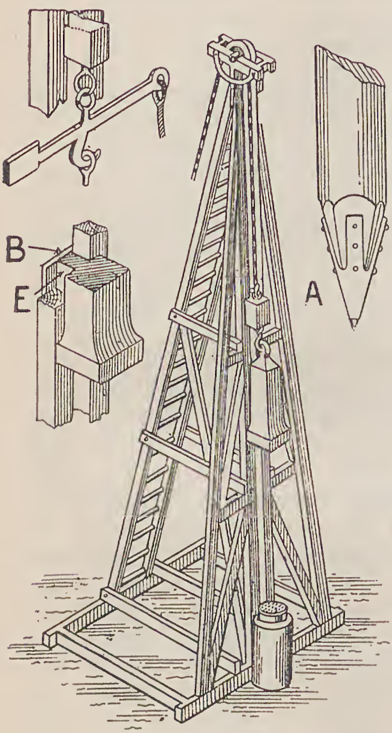


FIG. 7

(a) During the penetration of the pile, due to the blow, the soil is greatly disturbed.

(b) The less the interval between the blow, the less chance will the soil have to re-arrange itself, or (as it is called) "harden."

(c) It must, therefore, be evident that the more the soil "hardens" the greater will be the resistance to the further penetration of the pile, so that the machine which delivers its blows with the greatest rapidity will be the most successful in driving the pile into the soil.

The rapid driving of the pile is consequently to be desired, for thereby all the advantages of the increased resistance from "hardening," which will then take place only at the completion of the driving, is gained for the support of the load. The

engineers of the Public Works Department of New South Wales specify that the ram shall be 2,240 lbs. with a fall of 10 feet.

29. Steam Pile Driver. The steam pile driver is a machine with an action very similar to the well-known steam hammer. The ram is attached directly to the piston rod, and the whole machine rests upon, and is secured to, the head of the pile. It is very effective in its operation, for it delivers with great rapidity blows from a heavy ram (about 3,500 lbs.), through a very small fall (3 feet), and in works of an extensive character its use is attended with great economy.

30. Timber for Piles. A pile should be composed of hard, durable timber, free from knots, and should be capable of being obtained in long lengths. The various Australian hardwoods possess these qualifications, but Iron-bark and Turpentine may be mentioned as being especially suitable. Iron-bark is the best of the hardwoods, and is capable of great resistance to compression. Turpentine, on the other hand, while not being quite as strong, is yet, as far as resistance to decay is concerned, if anything, superior to Iron-bark. Experience has also shown that it is the least liable to the attack of marine borers, such as the teredo. This is due to an oleo-resinous layer, about ¼ inch thick, between the bark and timber, and, of course, if advantage is to be taken of it, the pile must be driven (as recommended by Mr. Maiden, F.L.S., late Government Botanist in New South Wales) with the bark intact. There is also another colonial timber, viz., Brown Pine, which is strongly recommended for piles, on account of its general immunity from the depredations of the white ants and teredo. The good qualities of these timbers, when buried underground, will remain durable and sound for a practically unlimited time, provided that uniform conditions of soil are existing. A timber cannot last in a soil that is liable to be dry at one time and wet at another, for there is nothing so destructive to timber as the alternative action of dry and wet. For this reason the tops of the piles should be as much below the surface of the soil as possible; in fact, they should be below the level of permanent moisture.

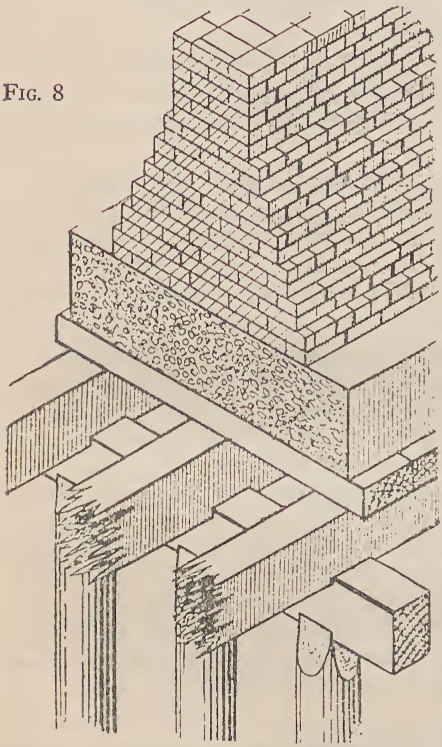
31. The Pointing of Piles. The lower ends of the piles are pointed to facilitate penetration when driving; and, when hard strata is to be passed through, the points should be shod with wrought-iron shoes, as shown by Fig. 7. Where the soil is soft (and this is, of course, usually the case), the iron shoe is quite unnecessary. The point should not be made too sharp, in any case, for it must be remembered that the point only

tends to penetration, and, beyond the requirements for driving, this is not needed. A suitable point is shown at A, Fig. 7.

32. Collars for Tops of Piles. Wrought-iron collars should be fixed (during driving) to pile heads, to prevent "brooming" and splitting.

33. Distance Apart of Piles. 2 ft. 6 in. centre to centre is the nearest distance apart that piles may be driven with safe results.

FIG. 8



34. Platform on Piles to Receive Footings. After the piles have been driven, the heads are sawn off, to a uniform level, and a platform of strong timber is built thereon. Fig. 8 shows the arrangement of the platform, and also the footings as built on it. A very commendable practice is to excavate round the heads of the piles for some depth, and fill in with tightly-rammed concrete.

35. Resistance to Crushing. All the timbers in the platform should be capable of resisting crushing from the load of the building.

36. Determination of Bearing Power of Piles. Bearing Piles may be driven, through a bad stratum, to an incompressible material, in which case they simply act as long supporting columns, and transmit the load on them to the safe, unyielding stratum; or they may be driven into a deep, yielding soil, until the friction against the sides becomes sufficient to practically prevent further driving, hence the load on them must be considered as being borne only by the frictional resistance. It will be clear, therefore, that in the latter case a great amount of judgment is necessary, in the determination of the safe load that may be imposed, whereas in the former instance

the piles, being only long columns, the estimation of the load depends on clear and well-defined conditions.

37. Piles in Yielding Soil. The consideration of the bearing pile in yielding soil may be dealt with first:—

W = weight of ram.
h = height of fall.
x = the depth the pile is driven by the last blow.
P = the greatest statical load the pile will bear without sinking further.
S = the area of average section of the pile.
L = the length of the pile.
E = the modulus of elasticity of the material of pile.

Then Wh = the energy and power accumulated by the ram at the end of its fall; and the distribution of this energy is as follows:—

(a) In overcoming the friction, against vertical guides of pile-driving machine, and against the air.
(b) In compressing the material composing the ram.
(c) In compressing the material composing the pile.
(d) In driving the pile against the resistance of the soil.

It is difficult to calculate with accuracy the loss due to friction against guides and air; and, for this reason, consideration of this portion of Wh is not included in the formulæ in general use. However, the loss is not great, provided that the guides and gear of the ram be in good condition, and it will be easily seen that the less the fall of the ram the less will be the friction both against guides and air, and the more nearly correct will be the result given by the formula. The amount given out in compressing the material of the ram is very small, and its effect is generally neglected. Professor Baker has, however, in his "Masonry Construction," included a formula which gives consideration to this loss. The following formula by Professor Rankine is among the best of the many in use:—

$\frac{P^2L}{4\,ES}$ = Portion of Wh spent in compressing the material of the pile.

Px = Portion of Wh spent in driving the pile.

$$\text{Then } Wh = \frac{P^2L}{4\,ES} + Px$$

Which, when solved, gives

$$P = \sqrt{\frac{4\,ESWh}{L} + \frac{4\,E^2S^2x^2}{L^2}} - \frac{2\,ESx}{L}$$

An experimental pile of carefully judged length and diameter should be driven with a suitable ram and fall, into the soil composing the site, and the last fall of ram and last pile penetration carefully noted. The foregoing formula should then be applied, and the ultimate bearing power of the pile will be determined. The safe bearing power may then be arrived at by dividing the ultimate bearing power by a factor of safety, which may be any number from 3 to 10, according to the importance of the case. Should the building be of an important character, it will be well worth the cost to impose an experimental load on the pile, and thereby put beyond question the ultimate bearing power. Having found what one pile will safely carry, it will be an easy matter to calculate the number that will be required under each footing. Care must be exercised that all piles are driven to at least the same resistance as the trial one.

38. Piles as Long Columns. Long columns usually fail by bending under the weight imposed, but in the case of piles this is counteracted or prevented by the lateral support afforded by the soil through which they are driven. This lateral support, of course, depends upon the stiffness of the soil, but (except in the case of very liquid soils) is generally sufficient to prevent bending, and so the supporting power will depend on the strength of the timber composing the piles. Therefore, to find the safe bearing power it will be necessary to divide the ultimate compressive resistance of the pile by a factor of safety which is usually taken as either 3 or 4. With piles driven through very liquid soils it will be necessary to estimate them as long columns without lateral support. The method of doing this will be explained later in the chapter dealing with columns.

39. Screw Piles. Timber piles have been dealt with at some length, because it is thought that the use of these will be found to meet all requirements of the builder, more especially as, in Australia, there is to be obtained in abundance such eminently suitable timber. There are, however, many different kinds of piles, such as wrought-iron, and cast-iron, in different forms, screw piles, and so on, but these are mostly of service only to the engineer in his more varied needs in this direction. Screw piles, so called because the lower or penetrating end consists of a screw or worm, may be noticed, because it is possible to get them into the soil without hammering, and they are of great use where the shaking or "jarring" of the usual driving process should be avoided. Screw piles are either wholly of iron, or are made with the lower end only of iron and a timber shaft. They are screwed into the soil by means

of a long lever attached to the upper end. The determination of their bearing power is best arrived at by screwing in a pile and experimentally loading it.

40. Sand Piles. A very useful method of improving the bearing power of a poor, earthy or clayey soil is that of drilling vertical holes, or bores, and filling them up with tightly rammed sand. Such are called sand piles, and there is no doubt that if properly executed they are just as good as if timber piles were used.

40a. Concrete Piles. Precast reinforced concrete piles are used extensively by bridge engineers. Concrete in the form of piers or piles are sometimes used under footings, to convey the load to a solid foundation. These piers or piles are used to save the cost of taking the strip footings to a solid foundation, and are spaced apart to suit conditions, the footings between being designed as beams.

41. Disadvantages of Piles. Some notice must be taken of the disadvantage which attends the use of piles for foundation in certain situations. The "jarring," or shaking effects, due to the driving process, causes in the case of water-holding soils a ready tendency to "jellify," and thus seriously reduce the bearing power of that adjacent. Again, with a clayey soil, if the piles be driven close together, a liability of upheaval of the surrounding clay is caused. It will, in consequence, be at once evident that where the site of the building is surrounded (as is most likely to be the case in a city) by existing buildings, extreme caution is necessary. A building in Chicago settled six inches during the driving of foundation piles in an adjacent site. Screw piles would be the best kind to use in such cases.

CHAPTER II

LIME AND CEMENT

42. Lime. Lime for building purposes is obtained by burning, or, more properly speaking, calcining, limestone. By the process of calcination, the carbonic acid and water are expelled, and quick or anhydrous lime results. Re-absorption of water is called slaking, and this action is attended in varying degrees, according to the nature of the lime, with a reduction to a powder, and a considerable increase in volume. Setting is the term applied to the hardening of the slaked lime after being mixed into a paste with water, and exposed to the air.

43. Kinds of Lime. There is a great difference in the various kinds of lime, and the degrees of, and conditions surrounding their setting or indurative powers. For the purposes of distinction a division into three classes may be made as follows:—

(a) Rich or pure lime.
(b) Poor lime.
(c) Hydraulic lime.

44. Rich Lime. Rich or pure lime is obtained from limestone of nearly pure carbonate of lime (such, for instance, as white marble and chalk), and is of a very quick or caustic nature, and, during slaking, heat is given out and the process is accompanied with plenty of noise and vapour. The slaked lime, if mixed to a paste and subjected to the action of air, will set, or, in other words, will be reconverted to a carbonate by the re-absorption of carbonic acid. This class of lime does not possess very great indurative power, and whatever there is of setting will take place only in the air, for it is soluble in water. Consequently it is utterly useless in subaqueous and subterranean work. Much of the lime used in the Australian States for building purposes is of the rich kind, and hence it is that mortar made from it never sets hard. Rich lime shrinks very much during setting.

45. Poor Lime. Poor lime is that kind which contains about 60 per cent. of pure lime and the balance of silica, in the form of sand, mechanically mixed together. The silica in this inert form has no influence on the setting power of the pure lime, and, hence, while reducing or making poorer the rich lime it

does not in any way improve it. It will thus be evident that, while it is not so quick, slakes slowly, and is not so soluble on account of the presence of sand, it is at the same time no better suited for moist or damp or important works than the rich lime.

46. Hydraulic Lime. Hydraulic lime is that kind which possesses the power of setting when in water or away from the action of the air. This characteristic of hydraulicity is resultant on the combination, during the burning process, of silica with some of the quick lime, forming what is known as silicate of lime, which, when hydrated, forms a hard body insoluble in water. This kind of lime is obtained by calcining limestone which contains clay (hydrated silicate of alumina) in varying proportions of from 10 to 30 per cent. As was mentioned in the last article (Art. 45), silica when present in limestone in the form of sand or flint, is useless, for it is quite inert and will not combine with the lime. Clay, however, contains silica in a soluble and useful form in combination with alumina; and, during the calcination of limestone containing clay, the silica therein combines with a proportion of the lime (after the carbonic acid and water have been expelled) and forms silicate of lime. As the temperature is increased to a high degree, alumina also enters to some extent into the combination, and a double silicate is formed. The proportion of clay present in the limestone, and the degree of temperature during calcination, have an important influence on the character of the hydraulic lime produced. When there is a large percentage of clay present, sufficient silica and alumina are provided to use up most of the quick lime in the formation of the simple silicate of lime, or, if the temperature can be raised high enough, the double silicate of lime and alumina, and possibly a separate combination of lime and alumina, called aluminate of lime. Such a lime will not slake and must be ground to a powder; then setting will take place immediately on the addition of water. A compound of lime and iron (if iron is present) may also be formed, but the presence to any great extent of metallic oxides and alkalis prevents the stone being burned at a high temperature on account of their action as fluxes causing fusion of the lime and alumina. In such cases a moderate temperature only can be used, and probably not enough to cause combination with the alumina; and the result will be a hydraulic lime composed of quick lime and silicate of lime possessing the power of slaking feebly, and afterwards (when made into a paste) setting. From the foregoing it will be evident that a limestone containing sufficient clay, and free from harmful amounts of

alkalis or metallic oxides, will have the necessary silica and alumina, and will admit of being burnt at a sufficiently high temperature to form the double silicate and the aluminate, and will consequently produce a good, strong, hydraulic lime. It is, however, very rare that the proportion of clay to the carbonate of lime is so well balanced in a limestone, and, moreover, an excess of metallic oxides and alkalis is very probable, consequently the hydraulic lime produced, as a rule, is the result of burning at a low temperature, and consists of the silicate of lime and a good proportion of quick lime, together with impurities.

PORTLAND CEMENT

47. **Portland Cement.** This very valuable cement is an artificially compounded and much improved form of the natural hydraulic lime. In the foregoing articles on lime, it has been pointed out that it is a matter of great difficulty to obtain limestone of such a character as to have its constituents properly proportioned in quantity, to render the production of good hydraulic lime a possibility. With the production of Portland cement this difficulty is overcome, for the proportion of each constituent is entirely under the control of the maker. The proper quantity of clay is added to the rich limestone to provide the alumina and silica for the necessary chemical action on the lime, and in the selection of the clay and limestone it is possible to avoid the presence of injurious amounts of the metallic oxides and alkalis so that burning may be carried out at a sufficiently high temperature.

48. **Process of Manufacture.** There are two methods of making Portland cement, which are known respectively as:—

(1) Wet process.

(2) Dry process.

The wet process consists of mixing chalk and clay thoroughly together in water until the consistency of a thickish liquid called "slurry" is reached. The "slurry" is then allowed to settle in tanks for the purpose, and the particles of clay and lime are deposited. After the complete deposition of the particles the water is run off, and the deposited mass is divided and made up into lumps, which are dried, placed in the kiln, and burnt at a great temperature to a condition of hardness. The lumps, which after being burnt are called "clinkers," are then ground to a very fine powder, and it is in this state that it is received for use by the engineer or builder. This process is now little used, having given way to the more improved dry processes.

49. The dry process is so named on account of the lime and clay being mixed together while in a dry state. When hard limestone is used, instead of the readily soluble chalk, mixing together by means of water is not possible. The clay is therefore in the dry process first roughly burnt in lumps to a condition of hardness, then added in the proper proportion to the limestone, and the whole ground to powder. By mixing the powder with water a pastelike mass is prepared, which in its turn is made up into lumps. The lumps are dried and calcined, producing the "clinkers" ready for the final grinding.

During recent years this process has been greatly improved, both in the speed of manufacture and in the production of uniformly high quality of cement. A modern cement-making plant may be thus described:—The limestone is first broken to small pieces in stone-cracking machines. These small pieces are conveyed by buckets on an endless belt or "conveyer" to a cylindrical revolving mill, in which they are reduced to a fine powder. From the mill the powder is taken by a conveyor to the weighing machine, where it meets the clay, which has also been reduced to a fine powder, and conveyed to the weighing machine. The lime and clay powders are mechanically weighed in the proper proportions, mixed together, and conveyed to the calcining kiln, which is a large revolving cylinder, lined with fire brick, and heated internally, to incandescence by gas. The kiln is inclined sufficiently to allow the lumps of clinker, resulting from the heating of the mixed powder of lime and clay, to gradually descend to the lower end, out of which they fall into the conveyor, which elevates them to the top of a cooling tower. The lumps of clinker pass by their own weight spirally down through this tower, and are all the time acted on by a cool draught of air, forced by a powerful fan up the centre of the tower. The clinker, which is quite cool by the time it gets to the bottom, is again taken by the conveyor to the grinding mill, cylindrical in shape, in which it is ground by revolution between flints, to the finest powder of Portland cement. A very important part of the cement works is the chemical laboratory, where are tested at frequent intervals specimens of the cement. The chemist in charge controls the whole process, and he alone has the adjustment of the lever of the weighing machine, which mechanically proportions the amount of the lime and clay. This lever is enclosed in a case, and only the chemist has access to it.

50. Chemical Composition of Portland Cement. The analysis of the chemical composition, though useful to some extent, cannot be taken as indicative in a complete sense of the quality

of the Portland cement. The value of an analysis is to show the presence of a sufficiency or otherwise of the important constituents, and whether those having a tendency to be harmful are in excess of the limit; but beyond that the analysis is not of much practical value. The analysis given below is that of a good Portland cement which successfully stood all the usual physical tests.

*ANALYSIS OF A GOOD PORTLAND CEMENT

Lime	Silica	Silica Insoluble	Alumina	Ox. Iron	Magnesia	Potash	Soda	Sulphur	Sulphur Triox'de	Carbonic Acid	Carbon	Water	Chlorides	Total
CaO	SiO_2	SiO_2	Al_2O_3	Fe_2O	MgO	K_2O	NaO_2	S	SO_3	CO_2	C	OH_2		
62·70	21·75	0·25	7·61	2·41	0·43	1·00		0·12	1·44	1·25	·10	·94	Traces	100·00

* Trans. Royal Soc., N.S.W., 1894, p. 268.

The various constituents as shown by the analysis may be divided into two classes as follows:—

(1) Essentials.

(2) Non-essentials.

The Essentials are the lime, silica, alumina, and iron.

The lime enters into combination with silica, and forms silicate of lime, double silicate of lime, and alumina.

With Alumina . . . Aluminate of lime.
,, Iron . . . . Ferrite of lime.
,, Water . . . . Hydrate of lime.

The Non-Essentials: The other remaining constituents are of little or no value and practically do not increase the indurative power of the cement. The non-essentials should not exceed 10 per cent.

The constituents are shown by the analysis, given above, to be in proper proportion, that is to say, there is shown to be enough silica and alumina and not much more than enough lime, whilst constituents likely to have injurious action are not in excess; but here the usefulness of the analysis ends, for it is not possible to decide with certainty that the combinations will be perfect. An estimate may be made from the

chemists' point of view as to the probability of perfect combination, by calculating the theoretical quantity of lime which each acid-constituent will require, and the following allotment of the lime shown by the analysis in question will be illustrative of this principle:—

For the	Silica	40·41
„	Alumina	12·51
„	Oxide of Iron	·84
„	Carbonic Acid	1·62
„	Sulphur trioxide	1·01
„	Sulphide	·21
		56·60

which taken from 62·70 leaves 6·10 per cent. of free lime. This it may be calculated will combine with water to form hydrate of lime. But the hydration of the excess of free lime not taking place, and such is not impossible but probable, there is the defect due to the presence of the free and uncombined lime. Again, during the setting of the cement decomposition of the more feeble compounds such as those of lime with alumina, and with sulphur, occurs, and more lime is used. The chemical analysis does not afford information as to the extent of these actions, and hence leaves much to be otherwise determined. It will, therefore, be evident that while serious discrepancies in proportion of constituents, as well as of the occurrence of injurious bodies, will be easily detected by aid of the chemical analysis, it does not in a complete and accurate manner indicate combinations which have taken place during the calcination, and what decomposition may afterwards take place when in use.

51. Deval's Hot Bath Test. The injurious effects, such as "blows," cracks, and disintegration due to the slaking or hydration and consequent increase in bulk of the quick or free lime, and to decomposition of the feeble compounds, occur during the setting, but in some cases where the lime is of a slow slaking nature these defects are not developed until after some considerable time has elapsed, so that the time usually allowed for the tests in cold water for soundness is not sufficiently long to allow of the development of the bad points, and a cement might pass for sound and afterwards turn out to be very poor. It has been discovered that cement sets much quicker in hot than in cold water—indeed, so much quicker

that a cement kept in hot water for 7 days will be as strong as if kept in cold water for 28 days. This knowledge is taken advantage of to accelerate the setting and so develop evidence of any bad qualities. Pats of neat cement, and of cement and sand in proportion of 1 to 3, are prepared, exposed in air for 24 hours, and then placed in hot water of uniform temperature of 180° to 200° Fahrenheit and kept there for 7 days. If at the end of that time there are no cracks or other indications of disintegration, the cement may be taken as sound. The pats should be about $\frac{5}{8}$ in. thick at centre, and tapering to a thin edge. They should be made on a non-porous surface, such as glass, and kept thereon until set.

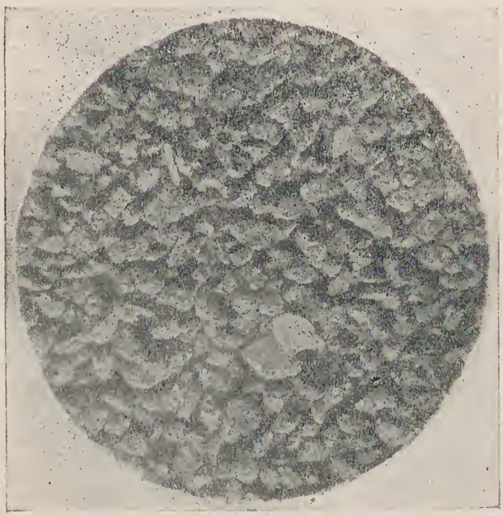


FIG. 9

RESIDUE OF NEW CEMENT ON NO. 120 SIEVE
(Magnification 19 diameters)

This test would be inconvenient for the architect, because of the difficulty of keeping up the temperature of the bath for such a period. The following method is one which may be used without a lot of trouble, and within a reasonably short time:—

> The neat cement is to be mixed with sufficient water to bring it into a plastic state; two balls, from $1\frac{1}{2}$ in. to 2 in. in diameter, are to be formed by hand and kept

in moist air for 24 hours. They are then to be put in a warm bath, and the temperature raised during a period of 30 minutes to boiling point. The water is to be kept with just as little heat as will suffice to maintain boiling for three hours. The balls are then to be taken out and cooled very slowly, after which they may be examined for cracks. The presence of cracks indicates want of soundness.

52. Texture. The proper degree of fineness of the powder is not less important than the correct proportion of the various constituents and their successful calcination. When used with sand, as it almost always is, the finer the particles the better,

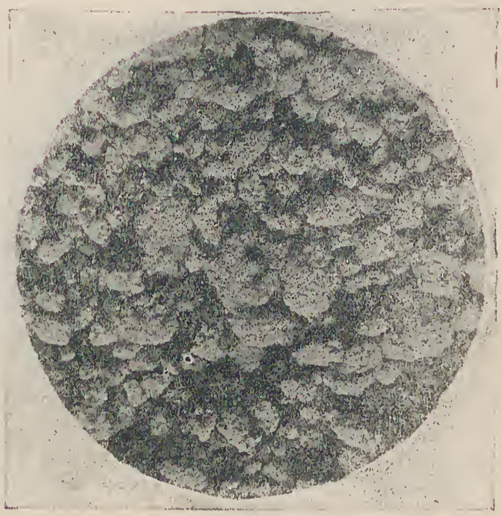


Fig. 10

Residue of Old Cement on No. 120 Sieve
(Magnification 19 diameters)

for it is to be remembered that it is to act as the cementing agent to hold the grains of sand together, and consequently the particles of cement to get round and in between the sand grains must be as small as possible.

To illustrate the importance of fineness of texture, Mr. Reid, in his valuable "Treatise on Natural and Artificial Concrete," cites a case where the cement of a certain degree of coarseness failed to stand the usual tests, but, on being sieved and the

coarse particles thereby removed, it successfully survived the same tests. It is generally agreed that the powder should be fine enough to allow of not less than 90 per cent. passing through a sieve having 14,400 perforations to the square inch. An average of at least two tests is necessary to form an estimate.

The residue should be carefully collected and preserved from dust. By examining it under a microscope having a magnification of about 20 diameters, some very important information may be gained. The clinker composing the residue should be of a uniform dark colour and the grains should be small. A light colour indicates a cement which is under burnt. White particles indicate free lime, gypsum, or Plaster of Paris. The residue is rarely free from these white particles, but, by comparison with clinker of a good cement, it can be decided when they are too numerous.

The photo-micrograph, Fig. 9, shows the clinker of a fairly good cement. The white particles can be fairly seen in the photo. Fig. 10 shows residue of a cement which was kept for about 12 months in a box. The clinker grains show a coating of the fine powder, and indicate that setting on a small scale has taken place.

53. Colour. The colour of the cement powder affords no indication as to quality, and any information in this respect can only be obtained after the "gauging" or mixing with water. Surface, as well as section, colour of the pat or briquette is taken notice of, and the tests are, as usual in other cases, made on cement. The pats of neat cement are examined as soon as setting has taken place, and a light grey external surface, with steel grey or bluish sections, shows a good kind. Dark greenish drabs or brownish colours are not good, and are expressive of inferiority. The pats of cement mixed with sand are not examined for the colour test until some considerable time (about six months) after the gauging, and the indications are fairly reliable. A light colour at the surface denotes sufficient lime, and a dark or brown colour is taken as being evidence of insufficiency of that constituent. Light indigo section indicates, in the case of English cement, good quality, whilst a good German make has a grey section. The best colonial cement has a grey section.

54. Tensile Strength. The degree of resistance possessed by the cement against tensile stress is an important point, and in all cases tests should be made. The briquette, as the sample to be tested is called, is made up into a form that will allow of its ends being gripped by jaws and pulled in opposite directions.

The most approved form of briquette is shown together with the jaws or shackles by Fig. 11. A, B are the jaws, and C indicates the middle or waist of the briquette at which breaking occurs. Fig. 12 shows an improved shape of briquette. The indents at the waist ensure fracture at the proper section. This waist is generally one square inch in cross section. Considerable importance attaches to the way in which the briquettes are made, and the particular conditions under which they are kept until put into the testing machine. A portion of the cement to be tested is mixed up neat, and another portion mixed up with sand in the proportion of 1 : 3. The quantity of water used should be not more than enough to enable it to be moulded. A good approximate rule for guidance is to take a handful and squeeze it, when, if the water is not in excess, it will be impossible to squeeze any out of the handful.

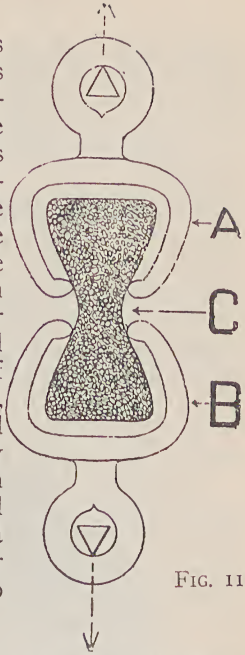


FIG. 11

An accurate method of determining the amount of water required for any particular class of cement is described by Mr. Roberts (Testing Engineer, Department of Public Works, New South Wales) in a paper published in the "Journal of the Royal Society of New South Wales," for 1894, as follows: "A weighed quantity of cement is placed in a mould into which a piston fits. Pressure* is then applied to the top of the piston by means of a screw, and a spring underneath the mould is depressed to a certain point; water is then poured in around the mould, then the water is first drawn in and afterwards the pressure is released, the cement is then taken out and weighed again, and the difference in weight will give the percentage of water absorbed, which is the percentage that must be used in making the briquettes." The above process is based on the principle that a given quantity of cement of one quality will, under a given pressure, absorb the same percentage of water. The uniformity of the pressure under which the mould, to form the briquette, is filled, is also a matter of importance. The pres-

FIG. 12

* 1400 lbs. per sq. inch for compression, and 2000 lbs. per sq. inch for tension.

sure is regulated and hence a standard is maintained by having the portions of the mould (the mould is made in two parts to enable the easy removal of the briquette when set) kept together by springs which open out after a certain degree of pressure is exceeded. By varying the amount of pressure used to compact the cement in the mould, the strength is affected to an appreciable amount. The best way is to always ram it in as much as possible. The most exact way to perform it is to use a machine called a Bohme Hammer, which automatically gives, each time, the same number of blows of a hammer, having a certain length of handle and weight of head. For testing purposes the sand used should be very clean; and to afford a basis of comparison it is necessary that a standard of fineness should be maintained. The usual method is to pass through a sieve of four hundred holes to the square inch and then through a second sieve of nine hundred holes to the square inch; and that which will not pass through the last sieve is used. As soon as sufficient set has taken place to allow of removal from the moulds, and this should occur before the expiration of the first 24 hours, the briquettes are placed, some in hot and some in cold water. Great care must be taken that the briquettes do not become dry before being placed in the water. Those in cold water are tested at 3, 7, and 28 day periods, while those in hot water are tested only at the 7 day period. It may be mentioned here that the cold water periods of immersion include the primal time in air; but the hot water 7 days is exclusive of the time given for air exposure. The average between 10 tests should be found at each date. The machines for producing the tensional stress are many in kind and varied in detail, but all aim at the exertion gradually and without shock of the force, and most of them are on the principle of the lever. One of the best in use is of German design, with a system of two levers, the power being applied in the form of small shot which fall at a uniform rate into a bucket supported at the end of the long arm of the primary lever. The short arm of the first lever is connected to the long arm of the second lever, and so the weight of the shot is multiplied in effect, and acts by way of connection between end of short arm of second lever of the jaws, on to the briquette to be tested. The value of the breaking force is found by weighing the shot (which it must be mentioned ceases automatically to run at the instant of fracture) and calculating the leverage.

A table is given with a view of affording some idea of what a good Portland cement should stand when subjected to tensional stress.

TABLE II

MINIMUM TENSILE STRENGTH OF GOOD CEMENT

In Cold Water	In Hot Water	Strength in lbs. per square inch		
		3 days	7 days	28 days
Neat Cement.	—	300	585	715
One of Cement to three of sand.	—	—	250	325
—	Neat Cement.	—	715	—
—	One of Cement to three of sand.	—	325	—

55. Compressive Strength. The resistance against compressive stress of a good Portland cement should be from 7 to 10 times its resistance to tensional stress. The tests for crushing or compressive strength are made on cubes of varying sizes from 1 in. to 9 in. edges.

TABLE II(A)

COMPRESSIVE STRENGTH OF PORTLAND CEMENT AND HIGH EARLY STRENGTH PORTLAND CEMENT

AGE AT TEST	STORAGE	MINIMUM COMPRESSIVE STRENGTH Lb. per sq. in.	
		Portland Cement	High Early Strength Portland Cement
3 days	24 hours in moist storage, 2 days in water storage.	—	4,000
7 days	24 hours in moist storage, 6 days in water storage.	3,500	5,500
28 days	24 hours in moist storage, 27 days in water storage.	4,500	6,500
28 days	24 hours in moist storage, 6 days in water storage, 21 days in air storage.	5,000	7,000

Taken from S.A.A.—A2. Test made on cubes 70.77 M.M.

56. Weight. Heavy cements are considered to be the best, but as an isolated test, the weight is not conclusive as to quality, for a good cement which has been ground very finely may be light in weight. Viewed, however, in conjunction with other qualifying tests, a cement should not be less than 100 lbs. per Imperial striked bushel. The manner in which the measure is filled will have an influence on the result when weighed, for, when poured in from a height the cement powder will be more dense, or compact, and consequently will be heavier than if just lightly filled in. The proper method is to let the cement fall from a hopper which is held 2 feet above the top of the bushel measure.

57. Time of Setting. Portland cements are either quick or slow setting. Those which take two hours or more to set are considered as slow setting. It is most necessary to have an accurate knowledge of the time which any particular cement that is being used will take to set, for a cement should on no account be worked after the setting has commenced. The most accurate method for arriving at the time at which the setting commences is to fill a metallic cylinder, 1 in. high, and 3 in. diameter, with the cement gauged with sufficient water to make a stiff paste. A needle, having a point ·039 in diameter, and 10½ ounces in weight, is then at intervals allowed to rest, point downwards, and length vertically, on the sample; and the moment at which the needle will fail to pass by its own weight through it, will mark the time of initial set. The cement is considered to be hard set when the needle fails to make any impression on the surface.

58. The foregoing table will afford a very good summary of the foregoing particulars relating to Portland cement. It is taken from the Portland cement test sheet used in the Department of Public Works, New South Wales, and shows the kinds of tests, and the standard required.

59. Most of the cement used at the present is made in New South Wales, Victoria, South Australia, and Tasmania. Portland cement is distributed in paper bags of one cubic foot capacity—24 bags to the ton. Most bags are endorsed with a seal indicating that the contents have been tested by a Government officer.

60. Plaster of Paris. The qualities of lime and Portland cement have been described at some length, for they are almost the only cementing agents used for holding stones and bricks together, and for concrete, in building construction, and consequently they become of great importance from the builder's point of view. There are, however, several other cements in

TABLE III

Ref. No.	Description of Tests	Standards Required
1	FINENESS { Residue on a sieve of 14,400 meshes per square inch	Maximum, 13 per cent.
	FINENESS { Residue on a sieve of 32,400 meshes per square inch	„ 25 „ „
2	SPECIFIC GRAVITY	Minimum, 3·000
3	SULPHURIC ANHYDRIDE	Maximum, 2 per cent.
4	RESIDUE INSOLUBLE IN HYDROCHLORIC ACID	„ 2 „ „
5	TIME OF SETTING—	
	At a temperature of...........Fahr. (commencement)	Minimum, 1 hour.
	With...........per cent. of water (set hard)	„ 3 hours, max. 12 hours.
	Consistency—20	
6	TENSILE STRENGTH—	
	Neat cement with...........per cent. of water.	
	After 1 day in air and 6 days in cold water of from 65° to 75° Fahr.	Minimum, 585 lb. per sq. inch.
	After 1 day in air and 6 days in Deval's Hot Bath of from 175° to 200° Fahr.	„ 715 lb. „ „ „
	Cement 1 part, Sand 3 parts, with...........per cent. of water.	
	After 1 day in air and 6 days in cold water	„ 250 lb. „ „ „
	After 1 day in air and 6 days in Deval's Hot Bath	„ 325 lb. „ „ „
	After 1 day in air and 27 days in cold water	„ 325 lb. „ „ „
7	COMPRESSIVE STRENGTH—	
	Cement 1 part, Sand 3 parts, with...........per cent. of water.	
	After 1 day in air and 27 days in cold water	„ 2,250 lb. „ „ „
	After 1 day in air, 6 days in water, and 21 days in air	„ 3,570 lb. „ „ „
8	EXPANSION OF NEAT CEMENT—	
	After 6 days in Hot Bath	Maximum, 0·10 per cent.
9	SOUNDNESS—	
	After 7 days in cold water; after 7 days in air; after 1 day in air, and 1 day in Deval's Hot Bath	To show no sign of cracking, crumbling, or alteration of form.

METHOD OF CONDUCTING TEST

4. Solution 20 per cent.
5. Estimated with a needle .039 in. diameter, loaded with 10½ oz., bearing on a disc of neat cement 40 Mm. thick.
Gauged for one minute with 50 turns of mixing machine.
6. Temperature of water in cold bath, 65° to 75° Fahr.; in hot bath, 175° to 200° Fahr.
The briquettes are made with the Böhme hammer machine; the time occupied in completing the briquettes being limited to ten minutes.
The percentage of water used is based on the amount absorbed by the neat cement under a pressure of 2.000 lb. per square inch.
The Michael's shot machine is used for breaking the briquettes. The speed with which the weight is applied is at the rate of 100 lb. in 12 seconds.
The standard sand used is Nepean River sand, washed, dried, and sifted through a sieve of 400 meshes per square inch, and caught on a sieve of 900 meshes per square inch.
8. As measured by Bauschinger's Standard Expansion Apparatus.

use which, though not so generally useful as lime and Portland cement, are yet at the same time of use in connection with plastering and modelling work, and, therefore, deserve a little attention. The best known of these cements, is **Plaster of Paris.** It is prepared from **Gypsum**, an hydrated sulphate of calcium ($CaSO_4 + 2H_2O$) which is found in a state somewhat resembling rock salt, and from nearly transparent to white, and in colours of greys, yellows, and browns. When pure white it is called **Alabaster**; when crystallised in flattened prisms it is known as **Selenite.** Plaster of Paris is prepared by calcining or exposing the Gypsum in ovens heated to a temperature of about 200° Centigrade, by which the water of crystallisation is nearly quite expelled, and it is afterwards reduced by grinding to a powder, after which it is ready for use. When mixed with water it hardens very quickly by the reformation of the original hydrate. The Gypsum is often mixed with a percentage of carbonate of calcium, but this addition by no means impairs the value of the plaster, for in such cases the acid of the carbonate is expelled (at the same time as the crystallising water of the sulphate), and quicklime in addition to sulphate without water results. If the heating is carried on at a higher temperature than that mentioned above, the re-hydration takes place very slowly, and the setting quality is interfered with; it is therefore necessary to avoid that which is over burnt. During the setting of Plaster of Paris an expansion of about 1 per cent. occurs; this may be demonstrated by filling a small glass of the freshly gauged plaster, tightly corking same, and putting on one side until setting has taken place, when it will be found that the bottle will be cracked and burst from the increase in volume of the plaster. Plaster of Paris is useless for work in damp positions, for it is soluble at ordinary temperature in water. It may, however, be remarked that as the temperature is increased the plaster becomes less soluble—at 150° Centigrade it is nearly insoluble in water. Plaster of Paris is made in three qualities—superfine, medium, and coarse.

61. Keen's Cement. This cement may be said to be a very much improved kind of Plaster of Paris. It was discovered by replacing the residual water of Gypsum by certain saline bodies, such, for example, as alum (which is a double sulphate of alumina and potash), that the hardening properties would be much increased. Keen's cement is made by mixing up the Plaster of Paris with a strong solution of alum, re-exposing in a much higher temperature than in the case of the plaster, and then re-grinding to a fine powder. Keen's cement sets very quickly, and becomes hard enough to receive a high

polish. Keen's cement is made in three qualities—superfine, medium, and coarse.

62. Parian Cement. This is a cement of much the same character as Keen's, but it is claimed that it works much freer when being used—that is to say, it is not so stiff during the period between being mixed and before hardening. It is made with Plaster of Paris in a similar manner to that described in the last article (61), the difference being that a solution of borax (biborate of soda) is used instead of alum. Parian cement is made in two qualities—superfine and coarse.

63. Cements not included in the foregoing Articles. Under this head may be noticed cements, which, owing to the almost general use of Portland cement, are not now much used, but which are of sufficient importance to deserve a little attention. Materials are obtained which required very little preparation to render them suitable for use as cements. The most notable is found in the form of concretionary nodules of argillaceous limestone known as **Septaria,** which, when calcined and reduced to a powder, make a cement somewhat like Portland cement, but, of course, not nearly so good. This particular kind of cement is known as **Roman Cement,** and was very extensively used prior to the introduction of Portland cement. It is not much used in Australia, but it is interesting to note that the Septaria have been found at Geelong, in Victoria, and that good cement has been produced from them. **Magnesian Limestone**, or Dolomite, if calcined (at a temperature which is below a dull redness) and reduced to a powder, makes a good hydraulic cement. **Puzzolana** is the term given to a material found in France and Italy. It is really nothing else but earth burnt through volcanic agency, but it is of great value when mixed with fat lime for making mortar, giving to it the quality of hydraulicity. The same result may, however, be obtained by reducing bricks, Terra Cotta, or such other kinds of burnt clay, to a powder and mixing with fat lime.

CHAPTER III

MORTARS AND CONCRETES

64. Sand. As sand, or some substitute for it, is used in the preparation of the various mortars and concretes, it will be best to deal with it and its various permissible substitutes first. Sand is comminuted stone in loose grains not sufficiently fine to be dust, and occurs in three kinds, which may be classified as follows:—

(a) *Siliceous,* the detritus of silicious or quartz stone.
(b) *Argillaceous,* the detritus of clayey stone.
(c) *Calcareous,* the detritus of limestone.

That which is generally found and usually used is Siliceous—and, indeed, this is the only one of the three kinds which has the qualifications to fit it for use in constructive work. The others are very fine—almost dust—and are not sharply crystallised. The grains of sand should have sharp edges and rough surfaces, and be thoroughly clean, for foreign materials, such as clay and organic matter, clinging to them, prevent the adhesion of the lime or cement. The grains should also be fairly coarse, the degree of which may be taken to be about that of the standard sand for briquette tests. (See Article 54, *ante.*)

65. Sand is obtained for building purposes from sand hills, or banks, pits, river beds, and by crushing sandstone. Sea sand is objectionable on account of the presence in it of salt, which causes it to be continually damp.

Hill bank and pit sand is sharp and gritty, but is liable to be associated with clay and other such impurities necessitating careful washing before using it.

River bed sand is clean, but is not sharp, the grains being rounded by the action of the water.

Hard white sandstone, crushed, makes an excellent sand, for it is—unless in exceptional cases—clean, and at the same time coarse, rough and sharp-edged in its granulation. The question of the efficiency of crushed sandstone for sand was exhaustively entered into during the proceedings of the Public Works Inquiry Commission, New South Wales, 1896,* and it was clearly shown that it answered well when made into mortar with cement.

66. Tests for Quality. In ordinary circumstances it is con-

* See pages 268 and 283 of the proceedings.

sidered sufficient to depend as to its gritty or sharp character on the sense of touch by feeling it with the fingers. The use of a microscope will, however, be more satisfactory in the case of important tests, as the condition of the grains can thereby be accurately ascertained. Fig. 13 is a photomicrograph of the fine-grained sand mostly used in Sydney, and obtained from Botany. Fig. 14 is a photomicrograph of the well-known valuable sand from the flats of the Nepean River at Emu Plains, Penrith. Fig. 15 shows crushed Sydney sandstone prepared and sifted to the standard size. These photographs show that the Nepean is the best. The grains are clean and sharp. It has been found that this sand, when standardised, gives the highest co-efficient of strength. The crushed sandstone has its grains coated with the fractured matrix of the stone, and this, no doubt, prevents a sound adhesion of the cement to them. The Sydney sand, while being very clean, has grains altogether too fine; in fact, the whole of the grains pass through the No. 30 sieve, so that there is absolutely none up to the standard size. Of the Nepean sand, as received, about 10 per cent. remains between the Nos. 20 and 30 sieves. Two per cent. stops on the No. 20. The rest all goes through the No. 30.

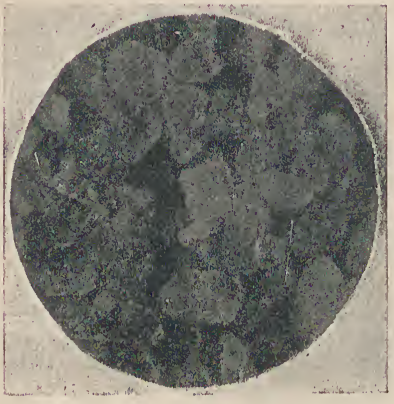


FIG. 13
SYDNEY SAND
(Magnification 19 diameters)

FIG. 14
NEPEAN RIVER SAND
(Magnification 19 diameters)

The cleanliness or otherwise of sand can be determined by taking about an ounce of it and rubbing it over a clean white sheet of paper, and if clean it will

not stain or soil the paper. The presence of salt is easily detected by washing some of the sand in some pure water—distilled for preference—and, after pouring some of the "wash" water into a test tube, add a little nitrate of silver, then, if the solution becomes cloudy, salt is present.

Fig. 15
Crushed Sandstone from Sydney
(Magnification 19 diameters)

A further test consists of shaking the sand thoroughly in a dilute solution of Sodium Hydroxide (Na OH) and observing the resultant colour of the mixture after it has been allowed to stand for a few hours. If the solution remains colourless, the sand may be considered satisfactory; on the other hand, if the solution is a dark colour the sand should not be used unless steps are taken to clean it.

67. Cleaning Sand. Coarse impurities, such as twigs, grass, etc., are removed by sifting. Washing is necessary where the

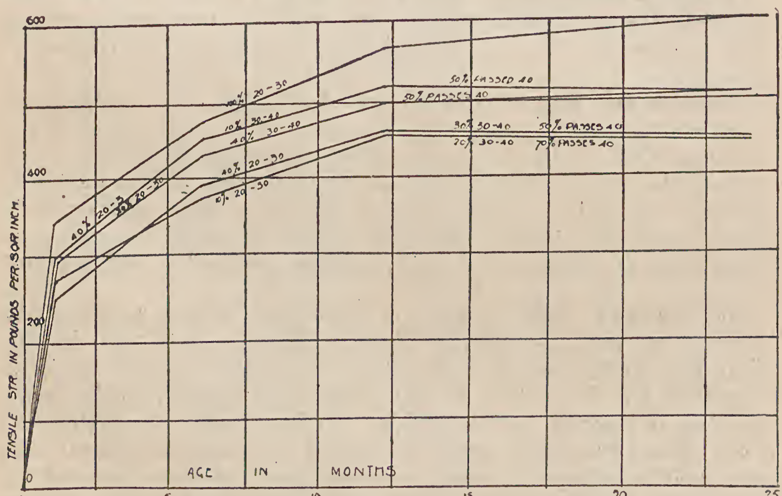


Fig. 16
The Diagram, Fig. 16, shows the comparative values of fine and coarse sands when used in cement mortars.

impurities adhere to the grains of the sand, and is accomplished by violently agitating the sand in a tank or large cask, at the same time passing plenty of water through it. The water is allowed to run into the tank or cask, so that there is a continuous outflow, by which means the foreign matter is removed in solution or in very fine particles.

68. Materials used instead of Sand. It is not always possible to obtain sand for use in making mortar, and it becomes necessary to provide something to take its place. The materials which are used instead of sand are:—

(a) *Coal Ashes* from furnaces and forges.
(b) *Breeze or Coke* crushed to a coarse powder.
(c) *Burnt Clay* crushed to a coarse powder.
(d) *Scoriae* } from ironworks, crushed to a coarse
(e) *Slag* } powder.
(f) *Road Grit.*

Coal Ashes, provided that wood ashes (which are bad on account of the presence of alkalis) are not mixed with them, are good for using with lime to make mortar. Ashes should be well sifted, for there is great liability of impure matter being present. Ashes are also used to darken the mortar for pointing where according to taste a black joint is needed.

Breeze, though not often used, makes a good substitute for sand, especially where crushing strength is not of importance.

Burnt Clay, which, after all, is only brick, is much used where a dearth of sand occurs. It should be thoroughly burned and crushed to be something like a coarse sand in particular size.

Scoriae and Slag, if properly crushed up, help to make good, hard mortar.

Road Grit is generally the detritus of hard paving stone (often the very hardest, such as quartz) and makes excellent mortar, the only condition being that it is most necessary to guard against impure materials, such as organic matter of street refuse, manure, etc. It should be well sifted and washed.

69. Casters' Sand from iron foundries makes an excellent mortar for use in localities liable to frosts. It is well known that the mortar made from lime and ordinary sand is disintegrated by the action of the frost, and consequently much trouble is caused to the builder. It has been found that the sand which has been used for casting will make a mortar that is not affected by the frost, so that it will thus be possible to overcome the difficulties which have in this particular matter been met with in such districts, as, for instance, the mountainous and southern parts of New South Wales.

MORTAR.

70. Constituents. Mortar is made up with sand (or its substitute) and either lime or Portland cement. *Lime Mortar* is generally composed of two parts of sand and one part of lime. The lime should be slaked in a box or tank, passed through a fine sieve while in a liquid form, and then mixed with the sand. By this means the slaking is conducted in a clean way, and the sifting prevents any unslaked particles of lime from passing into the mortar and subsequently causing damage by expansion. Unfortunately, however, this desirable method is not always adopted, for, it is common practice to just make a heap of lime, surround it with sand, slake it, and immediately mix the whole together. The constituents should be thoroughly mixed together. In all large and important works the mortar is mixed in mills, which may be briefly described as large circular revolving pans with large grinding rollers working in them — the motion being by steam power. These mills are very economical and especially when burnt clay, brick, slag, breeze, etc., are to be crushed. It is necessary to allow the mortar to stand for at least 6 days before using it. Coloured mortars are sometimes used. Care should be taken to see that the pigments used will not bleach when exposed to the atmosphere. *Cement Mortar*, usually called cement compo, is composed of 1 part of Portland cement to either 1, 2 or 3 parts of sand as the strength requirements vary. One part of cement to three of sand is the proportion mostly adopted. The sand after being washed (if not naturally quite clean) is measured out, and then the cement in its proper quantity is thrown on top of it. The lot is then turned over and mixed while dry, and afterwards the water, which must be quite clean, is added, turning and mixing going on all the time. Cement mortar is also mixed in mills, when the circumstances of work in hand render such a course economical. Unlike that made with lime, cement mortar should be used immediately on being mixed up, and on no account should it be allowed to stand sufficiently long for setting to commence. The use of too much water is to be avoided. To prevent the incorporation of unclean and foreign matter, mortar of whatever kind should not be made up on the ground, as it often is, but on a timber platform, which should be near to the place where the mortar has to be used.

71. Grout. With a view of having all the spaces between bricks thoroughly filled up, it is the practice to reduce the mortar to a liquid condition with water, and so pour it into the space. The mortar when so liquified is called "grout." It is also used for filling the spaces round dowels and joggles,

and for running into the grooves of the joints in masonry work.

72. Strength of Mortar. Mortar is an important factor in the strength of masonry and brickwork, holding, as it does, by its adhesive and tensile qualities the stones and bricks together, and compressive resistance by transmitting as the bedding material the compressive stress from top to underneath stones or bricks. The strength of a wall or pier, therefore, to a great degree (unless in the case of stones, most accurately wrought, and with thin joints) depends on the strength of the mortar, consequently a standard should be observed in calculations of important works, and frequent tests made to ensure adherence thereto.

73. A Table is given herewith which will be illustrative of the strength of cement mortar, made with good cement and sand of the quality usually used in work of a good character:—

TABLE IV *

Showing strength of Portland cement mortar composed of 3 parts of sand and one part of cement.

Sand put through sieve of 400 holes to sq. in. and caught on one of 900 holes to sq. in.

Kinds of Sand	Tensile strength in lbs. per sq. in.				Compressive strength in lbs. per sq. in.				Transverse strength in lbs. per sq. in.			
	30 dys	90 dys	6 mth	12 ms	30 dys	90 dys	6 mth	12 ms	30 dys	90 dys	6 mth	12 ms
Botany	134·7	172·1	201·54	224·42	1932·0	1617·0	2068·7	2025·9	280·5	373·3	457·5	546·2
Liverpool	143·5	165·8	204·7	238·5	1240·7	1569·4	1887·1	1612·9	277·1	381·75	480·9	440·6
Emu Plains (Nepean Sand)	201·14	234·4	280·3	272·0	1854·1	2242·0	2459·9	2674·2	376·9	545·5	510·9	562·5
Crush'd sandst'e	152·74	216·5	244·3	286·5	1100·6	1671·5	1499·4	1532·3	288·6	441·9	516·7	587·4

Where strength is of any importance lime mortar is not used, for it is very weak when compared with the Portland cement now so easily—and indeed cheaply—obtained. It is a matter of difficulty to generalise the adhesive strength of mortar, for the material to which adherence is to take place will have an influence on the result. For instance, a mortar of a certain kind will adhere to a rough, porous stone much better than to a hard, close-grained stone, such as basalt; or to a sandstock, or wire-cut brick, than to a hard glazed facing brick. It will, therefore, be clear that the adhesive strength will vary for each different kind of stone or brick, or other material. As far, however, as the mortar itself is concerned, it

* Compiled from valuable evidence given by Professor Warren, of the Sydney University, before the Public Works Enquiry Commission. See minute of proceedings, page 268.

will be safe to reckon that its adhesive power will increase directly as the tensile strength increases—that is to say, the more the tensile strength of a mortar the better will be its adhesive power.

74. **There can be no doubt** that the efficiency of mortar as a binding material is not generally valued to its full extent. A very interesting and valuable series of tests were carried out in India some years ago by Lieut. E. W. Creswell, R.E.* on beams built of brick in mortar, and the results were surprising. The lime used in the mortar had, when mixed with 1½ parts of sand, a tensile strength of 50 lb. per square inch at one month, and 65 lb. per square inch at two months. It will thus be seen that when compared with Portland cement such a lime is very weak. In the experiments in question the mortar was made up with two parts of lime and one part of sand. The beams were 15 ft. long, and had a clear span of 10 ft., so that the bearing at each end was 2 ft. 6 in. They were 2 ft. 6 in. x 2 ft. 6in. in cross-section, and the bricks were laid, or arranged, in English Bond.† Fifty beams altogether were built and tested, and they were classified in five divisions, according to thickness of joint in brick work. That is to say: Ten were built with joints 1/16 in. thick; ten with ⅛ in. joints; ten with ¼ in. joints; ten with ½ in. joints; and ten with ¾ in. joints. They were built on solid abutments, and on a centre, as it were, of earth, which was removed just before the imposition of the test load, so that they might have a free span. The beams were from nine to eleven months old, and it may be added that the load was applied at the centre of the span. The results are shown by the following table:—

TABLE V

Showing strength of Beams of Brick built in Lime Mortar. Beams 15 ft. long, 10 ft. clear span, 2 ft. 6 in. x 2 ft. 6 in. cross section, built in English Bond, Load applied at centre of span.

	Thickness of Joints				
	1/16in.	⅛in.	¼in.	½in.	¾in.
Average weight in tons which broke beams.	6·92	7·79	8·12	5·22	4·92

The dead weight of each span of beam was a little over 3 tons.

These tests serve to show that brickwork when carefully built has a very fair amount of strength, and also that joints about ¼ in. thick make the strongest work.

* For detailed description of these tests see "Roorkee Engineering Papers."
† See Articles hereinafter for description of bond of brickwork.

75. The following table, showing the adhesive strength of cement mortar has been kindly supplied to the author by Professor Warren, by whom the tests were made at the Engineering Laboratory of the Sydney University:—

TABLE VI

Summary of tests of Adhesive Strength of Cement Mortars to Bricks.

Description of Materials used in Testing	Mean of six tests giving the Adhesive Strength in lbs. per sq. in.			
	Cement	Sand	7 days old	28 days old
Cement neat	1	—	168	213
„ with crushed sandstone	1	1	117	146
„ „ „ „	1	2	53	73
„ „ „ „	1	3	26	48
„ „ „ „	1	4	16	45
Cement with Bluestone Dust ..	1	1	79	136
„ „ „ „ ..	1	2	47	84
„ „ „ „ ..	1	3	34	45
„ „ „ „ ..	1	4	23	41
Cement with Nepean Sand ..	1	1	102	105
„ „ „ „ ..	1	2	38	45
„ „ „ „ ..	1	3	20	24
„ „ „ „ ..	1	4	19	24

The bricks used were made at St. Peters, near Sydney, and gave, when immersed in water, an absorption of 7 per cent. "Castle" brand of Portland cement used. Crushed sandstone put through sieve of 400 holes, and caught in one of 900 holes per square inch.

76. Contraction of Materials for Mortar. The bulk of mortar is less than that of dry materials from which it is made, and for purposes such as estimating cost and for providing for the complete filling up of the interstices between the aggregate in concrete, it is most necessary to be fully aware of the extent of this contraction. The Table VII affords some useful information.

CONCRETE

77. Concrete is the name given to a mass or body composed of gravel, pebbles, broken stone, or some other hard substance, cemented or bound together with mortar. Concrete may, therefore, be divided into two classes of constituents, viz.:—

(a) The *aggregate*, or the whole of the pieces of broken stone, gravel, or pebbles.
(b) The *matrix*, or the mortar which binds the aggregate together.

TABLE VII *

Contraction of Cement and Sand when made into Mortar.

	One of Cement to One of Sand	One of Cement to Two of Sand	One of Cement to Three of Sand
By admixture with water .	15·00	16·66	17·50
By admixture with each other	5·00	5·00	5·00
By the cement setting to hardness from condition of mortar	4·00	4·00	4·00
Total contraction of materials in percentage of their own volume . . .	24·00	25·66	26·50
Total ratio of contraction of materials in percentage of the volume of the mortar when set	31·5	34·53	36·05

* Portion of a table by Sandeman, p. 256, Vol. LIV, Trans. Institute Civil Engineers.

78. The aggregate may be composed of any of the following materials:—Broken stone, broken bricks, pebbles, breeze, and, indeed, any hard substance which may be broken up in the same manner as stone. Gravel and shingle from river beds are also very suitable. In building work the kind usually used is either hard stone, brick, or gravel. The material for the aggregate is reduced or broken by hand with a tool called a "knapping hammer," and also by means of stone-breaking machines driven by power. It is a matter of impossibility to evenly break the stone, and necessarily a variety of sizes, and also a quantity of very small pieces, which are reduced almost to sand, are produced. Screening is therefore necessary to obtain pieces within a certain range of size. In the case of machine stone-breakers a screening apparatus is attached, so that the pieces of different sizes are separated. When broken by hand the stone is usually screened also by hand. The aggregate should be well washed, so that any extraneous matter may be removed.

79. Size of the Aggregate. The gauge to which the stone or other material is broken varies according to circumstances, but mostly it is specified that the aggregate shall not be more

than $1\frac{1}{2}$ in. or 2 in. in size. Aggregate is, however, often made much larger in special cases, and, for such purposes as pavements, they are prepared so small that the largest pass through a $\frac{3}{4}$ in. ring.

It is generally admitted by authorities that it is best to leave the "Shivers" or smaller pieces in, than to screen the aggregate to have them all of the one size—that is to say, it is better to have the aggregate ranging in size from what will just fail to pass through a $\frac{1}{8}$ in. sieve, to $1\frac{1}{2}$ in. or 2 in., as the largest are specified to be. The argument in support of this being that the smaller pieces fit in between the larger ones, and so in a substantial manner aid to fill up the voids which would otherwise require to be altogether filled up by the matrix. Notwithstanding the above, $\frac{3}{4}$ in. gauge aggregate is generally used in reinforced concrete work.

It is a very important matter to accurately ascertain the percentage of the spaces of interstices between the aggregate, for it is this percentage of space which determines the ratio of the volume of the matrix to the volume of the aggregate. The table here following gives percentages in several kinds of material, but experiments will have to be resorted to in most cases to find the percentage of void:—

TABLE VIII *

Table showing ratio of Interstices in Aggregate for Concrete.

	Ratio of Interstices
Broken limestone, the greater part of which would be gauged by a 3 in. ring	50·9
Gravel screened (free from sand), small pebbles, and pieces gauged by a $2\frac{1}{2}$ in. ring	33·6
The above limestone and gravel well mixed in equal proportions	33·6
Sandstone varying in size between pieces gauged by a 4 in. ring and pieces gauged by an 8 in. ring	50·0
Sandstone varying in size between sand and pieces gauged by a 4 in. ring	34·0
The above two sandstones mixed in equal proportions	36·0

* Portion of table by Sandeman, p. 218, Vol. CXXI, Trans. Institute Civil Engineers.

80. The Percentage of Void in any kind of aggregate may be determined by filling a vessel of one cubic foot capacity, with the aggregate, and then pouring water in, so that all the interstices may be filled. The quantity of water required to fill the interstices will indicate the amount of void per cubic foot.

81. The Matrix or Mortar. The materials for and methods of making mortar have already been described, consequently it will at this stage be only necessary to deal with the question of proportion. It may, however, be noted that concrete is made with lime mortar as well as with cement mortar, though, of course, cement is the most used on account of its great superiority in the matter of strength and also hydraulicity. The author is aware of at least one large building just outside Sydney, the foundations of which are made with lime concrete, and it has answered quite well. There is also a house on the Blue Mountains, New South Wales, which has all the walls built of this lime concrete. These examples are only given to illustrate the fact that it is not only Portland cement that may be used in making concrete.

82. Proportion of Matrix to Aggregate. It is most important that the matrix should thoroughly fill up all the voids or spaces between the aggregate, and not only that, but also be sufficient to get between the pieces of stone and cement them together. About 10 per cent. is added to the percentage of void to ensure all voids being filled and sufficient mortar being provided to cement the aggregate together. Another thing also which must be remembered is that the mortar when set is less than the bulk of the dry materials (see Table VII). This percentage of contraction must be added to the percentage of void.

To illustrate the above:—

Let X = The percentage of void in any particular kind of aggregate.

„ Y = The amount of excess (usually 10 per cent.) to ensure presence of sufficient mortar to cement pieces together as well as fill all voids.

„ Z = The percentage of contraction of dry material when set into hard mortar.

„ A = Total percentage of volume of dry materials of matrix to volume of aggregate.

Then $A = X + Y + Z$.

The proportions for foundations and walls, roughly put, may be taken as follows:—

Aggregate (from $\frac{1}{8}$ in. to 2 in.), 5 parts; sand, 2 parts; cement, 1 part.

Aggregate (from $\frac{1}{8}$ in. to $1\frac{1}{2}$ in.), 4 parts; sand, 2 parts; cement, 1 part.

83. Mixing of Materials to make Concrete. The amount of each kind of material is determined by measuring in gauge boxes which are proportioned in capacity as the specified relative quantities of aggregate and constituents of the matrix. To make this quite clear, let it be supposed that the relative quantities of stone, sand, and cement are represented by the ratio 4 : 2 : 1, and taking the cement box to be 4 cubic feet, then the capacity of the sand and stone boxes would be 8 cubic feet and 16 cubic feet respectively.

Builders generally please themselves as to the shape of these boxes, since the only important matter is that of correct proportional capacity; but by way of completing the above illustration it may be as well to set down one arrangement of sizes which would provide for the above-mentioned proportional capacities:—

The cement box might be	2ft. x 2ft. x 1ft. =	4 cubic ft.
The sand box might be	4ft. x 2ft. x 1ft. =	8 cubic ft.
The stone box might be	4ft. x 4ft. x 1ft. =	16 cubic ft.

The process of gauging and mixing is carried out on a sawn timber platform as follows: The stone box is first filled with stone and then emptied, and the stone spread out so as to be level at the top. The sand box is then placed on top, is filled and emptied, and the sand heap levelled out in the same manner as the stone. The cement box is next placed on the sand, filled and emptied. The whole heap is then completely turned over from its position to another one on the platform and then back again. Water is then gently sprayed on to the heap while it is being twice again turned over on the platform. Care is to be exercised that too much water is not used, for excess washes away the fine and useful cement, and is otherwise injurious as pointed out in article 54, *ante*, and there should not be more water in the concrete than shall just show moisture on the surface when rammed.

The foregoing is descriptive of the process as accomplished by hand power, but (as in the case of mortar making) there are many kinds of concrete mixing machines which are thoroughly effective as mixers. Concrete mixers vary in size, and those generally used on large projects are big enough to allow of one or more bags of cement to be used in each batch.

A recent development is the establishment of central plants from which ready mixed concrete is available. The concrete is delivered in special trucks on which are mounted drums which revolve slowly and so agitate the mixture. It has been found that concrete so agitated does not lose any of its strength for a

period up to a few hours. Concrete should not be made up on a windy day, for the wind removes a great portion of the fine cement.

83a. Slump Test. The amount of water to be added should be decided by frequent slump tests. The slump test is carried out as follows:—

> The equipment necessary consists of a sheet metal mould, formed like a frustrum of a cone. This mould is 4 in. in diameter at the top, 8 in. in diameter at the bottom, and 12 in. high. The mould is open at the top and bottom. It is fitted with two handles, placed on the outside and opposite to each other. In addition to the mould, a metal rod $\frac{5}{8}$ in. in diameter and 21 in. long with a bullet-shaped point is required. In making the test, the mould is placed with its largest or bottom end on the mixing board. Concrete from the mixture being made up, is taken and put in the mould in layers of each about 4 in. deep. Each layer is worked with the pointed metal rod exactly 30 times. The mould, after being filled in this way, should then be lifted off immediately. As the mould is lifted, the concrete settles down, and when the mould is completely removed appears as a mass, more or less different in height to what it was when it was in the mould. The height of the mass should be measured and compared with the original height of 12 in. of the mould, and the difference noted.

The following slumps are given as indicating the proper amount of water to be used in the concrete for different kinds of work:—

For concrete to be laid in large masses, slump of	2 in.
Reinforced concrete, beams and slabs	4 in.
Thin vertical sections	8 in.
Thin confined horizontal sections	8 in.
For roads and pavements, hand finished	4 in.
Mortar for floor finish	2 in.

After making the test, if the slump be too small, more water can be used; if the slump be too great, less water can be used. The test is worth while because it can be shown that an excess bucket of mixing water may decrease the strength of concrete as much as if two buckets of cement had been left out; or, putting it another way, for every extra 1 in. in the slump, the water is increased 6 per cent. and the strength decreased 8 per cent.

84. Laying Concrete. The concrete should be mixed near where it is to be used, and then put in its place as quickly as possible—at any rate, it should be laid and rammed before setting commences. It is usual to remove it in barrows, or skips, from the mixing platform; and the "tip" or fall from the barrow or skip should not be more than 18 in. or 2 ft.—with a greater fall the heavier portion, such as the stone, has a tendency to get to the bottom of the body of the concrete, and thus destroy its uniformity of composition. After tipping from the barrow or skips it should be shovelled out, trodden, and rammed. Concrete is not laid in greater thickness than in layers 9 in. or 12 in. at a time. These layers should be perfectly horizontal, should be accurately set, and the surface of each should be thoroughly clean and wet before laying the next. Concrete should be protected, until fully set, from the effects of the sun; and rain should not be allowed to fall on it until after the initial set has taken place.

84a. Vibrated Concrete is the name given to concrete which has been subjected to vibration of high frequency (about 3,000 impulses per minute), but of small amplitude imparted as soon as placed in the forms. Vibrators may be either propelled by electricity or compressed air. The advantages arising out of the use of vibrators are:—

(1) Increased strength.
(2) Greater density and durability.
(3) Easier placement.
(4) Better surfaces.

(1) and (2) are likely, due to the fact that a much drier concrete can be placed with vibrators than without.

85. Strength of Concrete. Table IX, here following, has been compiled from valuable and interesting information contained in three tables,* showing results of experiments by Mr. John Grant, M.I.C.E., as to the strength of concrete. The quality of Portland cement has improved since these tests were made, and experiments made with similar aggregates, and under equally skilful supervision, would, it is certain, give much higher results.

86. Reinforced Concrete. The results of tests on concrete beams given in Table X will show what little weight-bearing power this material has when subjected to the bending stresses resulting from transverse loading. A floor slab or beam, by its own weight, together with its load, is so stressed that the upper portion is in compression and the lower part in tension. Concrete is very strong in compression, but comparatively very weak in tension, consequently the lower portion of the

TABLE IX

Showing Strength of Concrete Blocks.

The size of each block was 12 in. x 12 in.; and the concrete composing each was well rammed or compressed.

Cement weighed when sifted, 110·56 lbs. per imperial striked bushel. After seven days in water neat cement broke at 427 lbs. per square inch.

Materials for aggregates which it is presumed were so broken †as to contain a percentage of pieces sufficiently small to make enough sand to mix with cement to form matrix.	Weight in tons which crushed the blocks					
	Proportion 6 to 1		Proportion 8 to 1		Proportion 10 to 1	
	Kept in air	Kept in water	Kept in air	Kept in water	Kept in air	Kept in water
Ballast	80·50	91·00	61·50	76·00	48·50	48·00
Portland Stone	118·00	138·50	110·00	126·50	72·60	78·00
Granite	113·20	96·50	73·80	84·60	49·80	60·50
Pottery	109·20	136·50	97·50	118·00	90·00	100·00
Slag	110·50	111·00	85·20	70·00	60·00	52·00
Flints	116·00	126·00	103·50	117·50	70·00	98·00
Glass	99·00	112·50	65·00	94·00	53·00	75·00

* See Tables IV, V, and VI, page 297, Vol. XXXII, Trans. Institute Civil Engineers.

† Whether this was so, or not, was not made clear in the description of the experiment.

TABLE X

Showing results of tests made in Concrete Beams at the Sydney Technical College.

No.	Composition of Beams				Depth in inches	Breadth in inches	Span in inches	Age when tested in days	Breaking load in lbs.
	Metal	Ashes	Sand	Cement					
1	4	—	2	1	4·93	8·5	48	236	1200
2	—	4	2	1	6·25	8·625	48	230	1210

The tests were applied at the centre of the beams in each case.

TABLE XI

Table showing Compression Tests made on Cubes of Ash Concrete at Sydney Technical College.

No.	Sizes of Cubes in inches	Composition			Age in Days when tested	Crushing Load in lbs. per sq. in.
		Boiler Ashes	Sand	Cement		
1	6.00 x 6.12 x 6.19	3	1	1	290	1300
2	6.28 x 6.06 x 6.00	3	1	1	238	987
3	6.06 x 6.31 x 6.19	3	1	1	237	1133
4	6.06 x 5.89 x 6.25	6	—	1	260	393
5	6 12 x 6.18 x 6.19	6	—	1	246	440
6	6.09 x 6.06 x 6.22	6	—	1	246	486

beam soon opens out and collapse ensues. Of course, the beam or slab could be designed to carry the load, but unless the load and span were very small the size of the beam or slab would be inconveniently large, indeed, very probably too large for practical consideration. If, however, a material strong in ten-

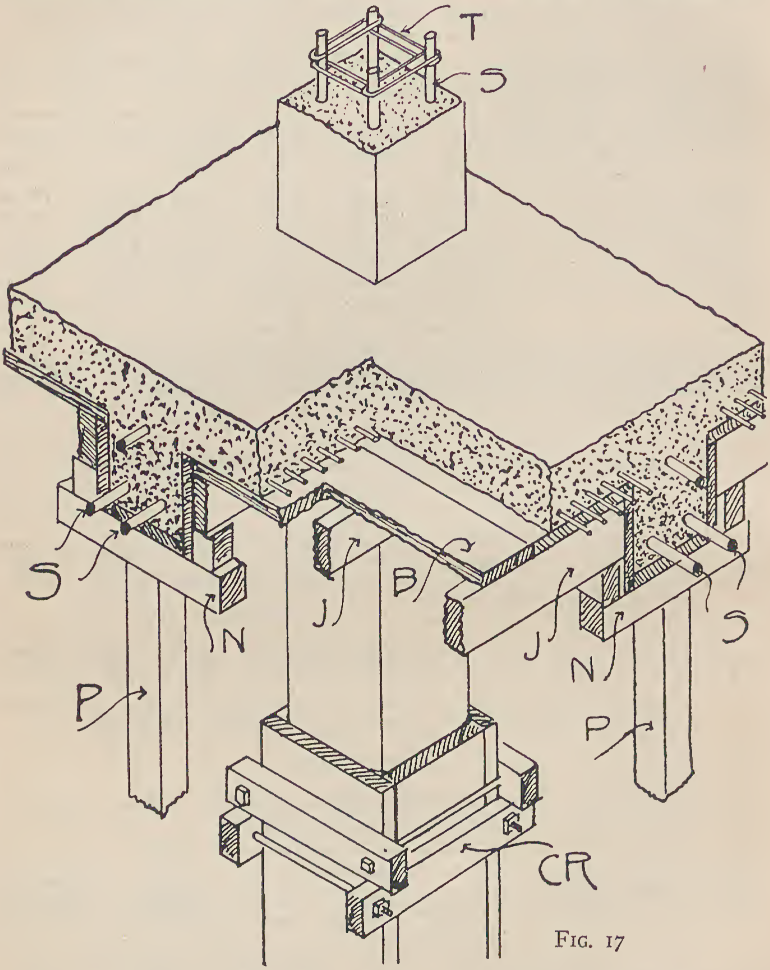


FIG. 17

sion could be combined with the concrete to strengthen it against tensile stress, the case would be altogether altered. This is exactly what has been done in recent years, and steel has been used in conjunction with concrete to reinforce it. The diagram, Fig. 17, is an isometric sketch, showing portions of columns, beams and floor, as constructed of reinforced concrete. It also shows the "false work" to support the concrete

until set. Fig. 18 is a view of a building of reinforced concrete in course of construction.

87. Calculations for Strength of Reinforced Concrete Beams. The following is a brief description of the principles involved in the calculation of the proper proportions of concrete and steel in the design of reinforced concrete beams. The student is recommended to read the chapter in the latter portion of this book on the design of girders, with a view to understanding the bending moments and moments of resistance, before proceeding with the study of what is to follow in this chapter.

Fig. 17 gives an isometric view of some "false work" to support the concrete. The column boxes or moulds are formed with boards 1¼ in. thick, held together at intervals of about 24 in. with cramps composed of 4 in. x 2 in. pieces, and ½ in. bolts, as shown by CR. The cases or boxes for the beams are also made of 1¼ in. boards, supported at intervals of about 6 feet, which in turn are supported by uprights from the ground or from the floor beneath. The needles also support plates on which rest the joists to support the 1¼ in. boarding, or centring

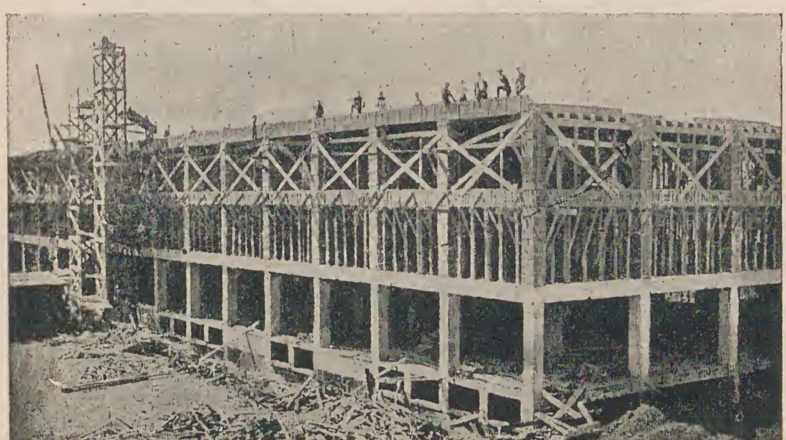


FIG. 18

for the floor slabs. The whole of the false work must be put up without nailing, to allow of being removed without shock to the concrete.

Generally speaking, no form work should be removed until 28 days have expired after the pouring of the concrete. In practice, however, the sides of beams are sometimes removed after 14 days.

The steel should conform to the S.A.A. standards for structural steel. It should have a modulus of elasticity of 30,000,000 lbs. per square inch.

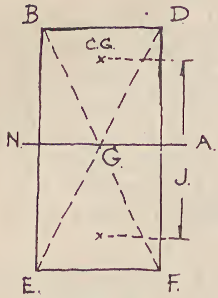


Fig. 19

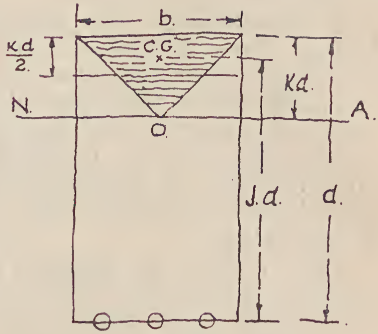


Fig. 21

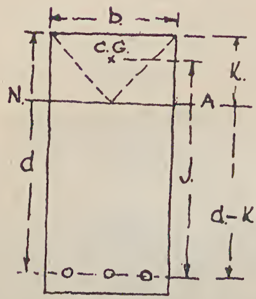


Fig. 20

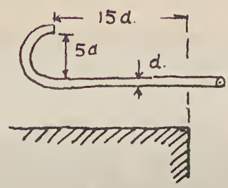


Fig. 22

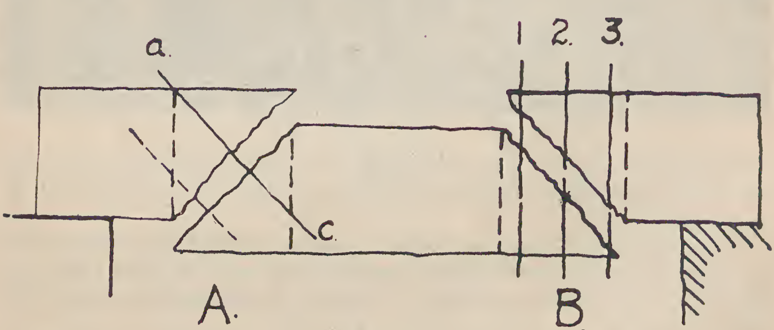


Fig. 23

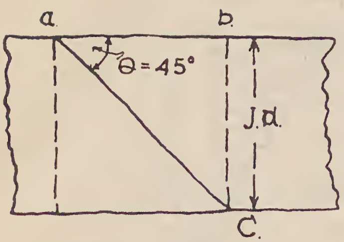


FIG. 24

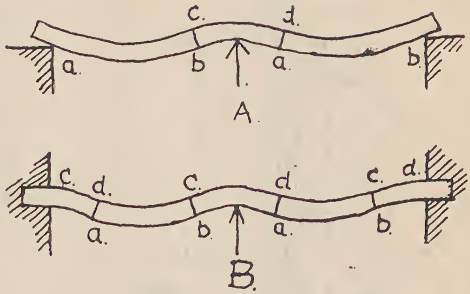


FIG. 25

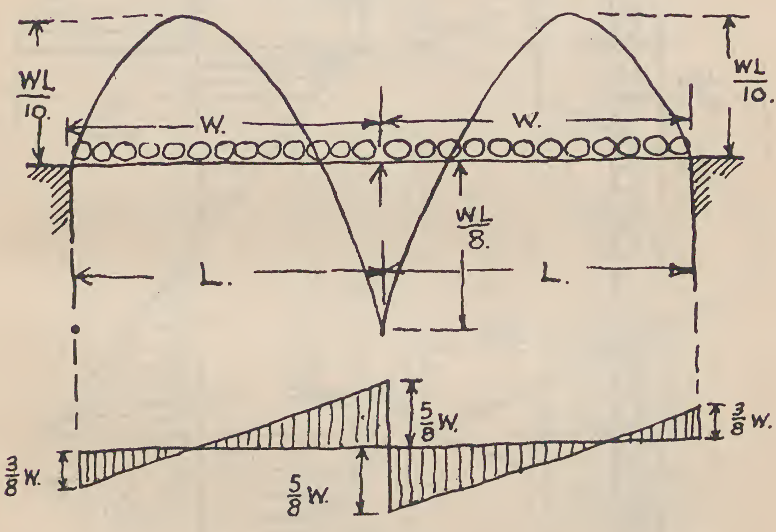


FIG. 26

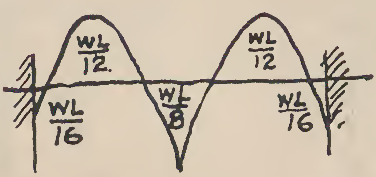


FIG. 28

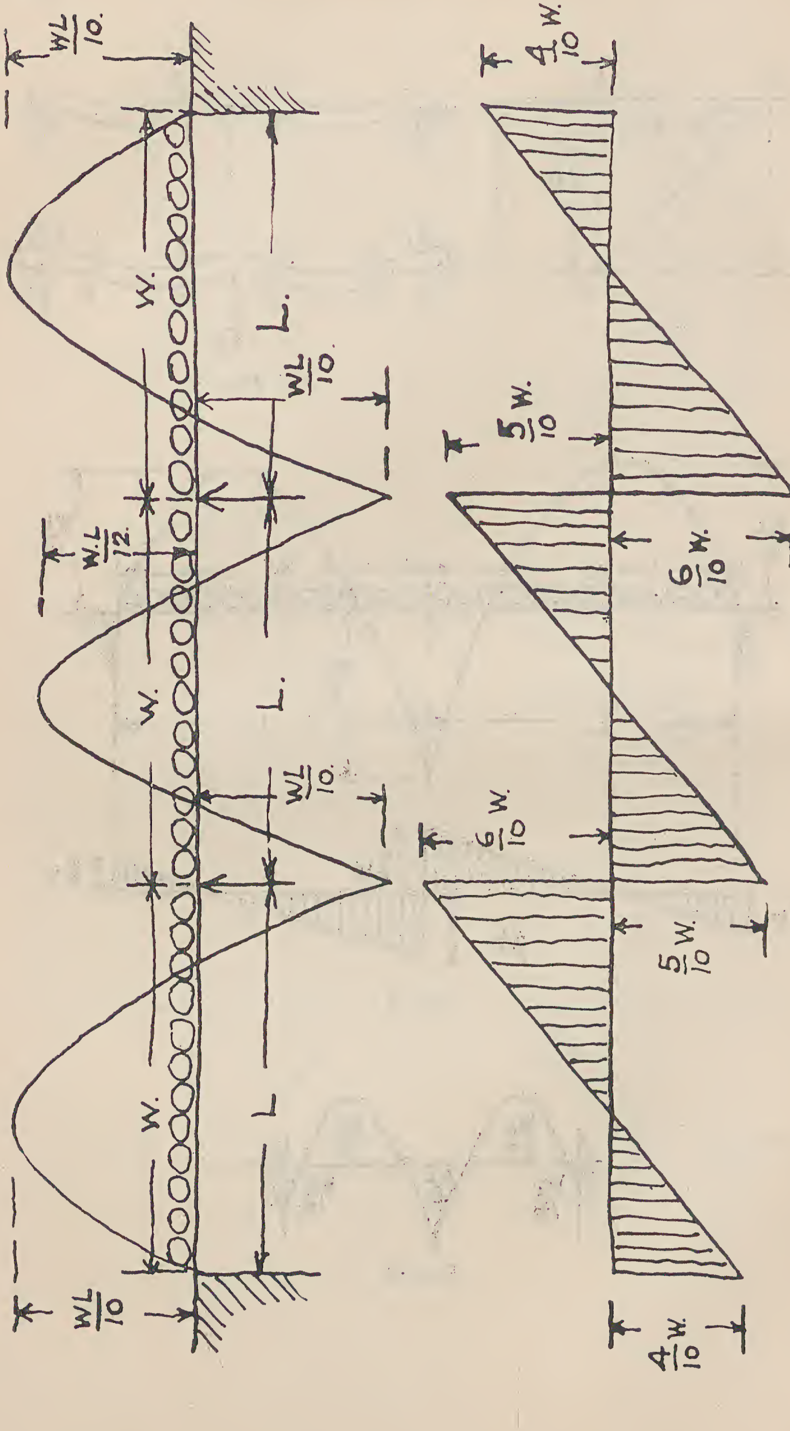


FIG. 27

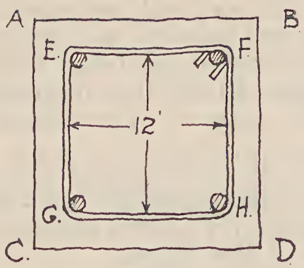


FIG. 29

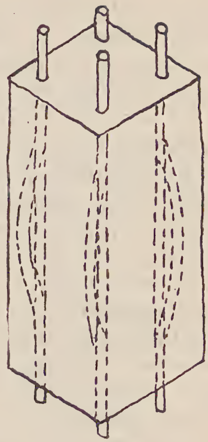


FIG. 29B

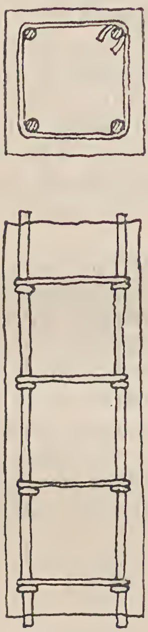


FIG. 29A

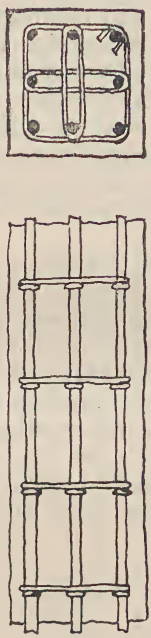


FIG. 30

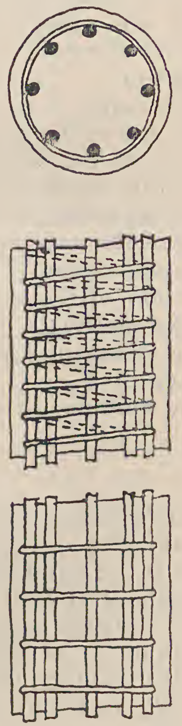


FIG. 31

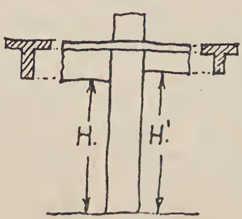


FIG. 32

The materials for beams, such as steel and timber, are equally strong in compression and tension, and the neutral axis coincides with the gravity axis of the beam section as shown by Fig. 19. In this figure, BDEF is a rectangle, the gravity axis of which is at the centre G. The neutral axis, NA, passes through G.

When, however, the beam is to be composed alone of a material like concrete, which is approximately ten times as strong in compression as in tension, the neutral axis no longer coincides with the gravity axis of the section.

It is necessary to find this position of the axis, because upon it depends the length of the lever arm J. Fig. 20 shows diagramatically the tension and compression forces in a steel reinforced concrete beam. Assuming the N.A. to be in its proper position, the concrete above it will be devoted to resisting the compression strength, whereas the portion below the N.A. will merely hold the steel in position to allow of the latter devoting itself to resisting the tension stress. The lever arm J. will extend from the centre of gravity of the group of effective fibres in compression to the centre of the steel reinforcement.

The depth d is the distance from the centre of the steel to the top of the beam. The distance k to the N.A. down from the top of the beam, and the distance d-k from the N.A. to the centre of the steel, are parts of d in a proportion to each other, depending on the proportions to each other of the shortening of the concrete and the expanding of the steel under any particular stress. The relative shortening of concrete and the extension of the steel depends on the relative elasticities of the two materials. The elasticity of the materials is expressed by the constant known as the modulus of elasticity, usually denoted by E.

The modulus of elasticity is

$$E = \frac{\text{stress}}{\text{strain}}$$

the stress being the load and the strain being the elongation. The modulus of structural steel determined by many experiments is, on the average, 30,000,000 lbs. per square inch. All materials stretch or shorten or deform, as it is called, under stress, causing compression or tension, and concrete is no exception to the rule. As would be expected, however, its elasticity is much below that of steel, and it varies, of course, according to the quality. According to the S.A.A. Code C.A.2, when the compression strength of concrete at 28 days exceeds 1,500 and does not exceed 2,200 lbs. per square inch, the modulus of elasticity of concrete may be taken as 2,000,000 lbs. per square inch. When the concrete at 28 days has a strength

of at least 2,200 but does not exceed 2,900 lbs. to the square inch, the modulus of elasticity may be taken as 2,500,000 lbs. per square inch. When the strength exceeds, at 28 days, 2,900 lbs. per square inch, the modulus of elasticity may be taken as 3,000,000 lbs.

The ratio of the modulus of elasticity of concrete to the modulus of elasticity of steel is called n. For the above moduli for concrete, and taking steel as 30,000,000 lbs., the following values of n are:—

Concrete 1,500 to 2,200 lbs.

$$n = \frac{30,000,000}{2,000,000} = 15$$

From 2,200 to 2,900

$$n = \frac{30,000,000}{2,500,000} = 12$$

From concrete over 2,900 lbs.

$$n = \frac{30,000,000}{3,000,000} = 10$$

With well selected fine aggregate and ¾ in. blue metal coarse aggregate, it should be possible, with a mixture of 1 : 2 : 4, to secure concrete to stand 2,200 lbs. at 28 days old tested on a standard cylinder 4 in. in diameter and 9 in. high. With this compression strength per square inch, n can be taken as 15.

The S.A.A. Code C.A.2 allows 0.35 of f'_c the compression strength, as the safe load to be borne by the extreme fibres in compression in a beam or slab. 2,200 lbs. x 0.35 = 770 lbs., which is usually taken as 750 lbs.

If two bars, one of concrete and the other of steel, when n = 15 be stressed so that the elongation is the same amount in each, the stress on the steel will be 15 times as great as the stress on the concrete.

It will be obvious that in a beam comprised of steel bars embedded in concrete, the stretching or shortening due to stress must be the same in both materials, otherwise cracking would occur and the strength be seriously affected. It is to prevent this and yet to combine the greatest strength of the two materials in a beam that it is necessary to have the proper percentage of steel to concrete, and to have the calculations based on the proper position of the N.A. and the exact length of the lever arm j.

When n = 15

the proportionate stretching of concrete, having an allowable stress of 750 lbs. per square inch, to steel, having an allowable stress of 18,000 lbs. per square inch, will be as

$$750 \quad : \quad \frac{18,000}{15}$$

$$\text{or } 750 \quad : \quad 1,200$$

The position of the N.A. can be calculated from the following formula:—

$$k = \sqrt{2pn + (pn)^2} - pn$$

p in the formula is the ratio of the area of steel to area of concrete as

$$p = \frac{A_s}{bd}$$

in which A_s = area of steel and bd = area of concrete.

It will be necessary to determine the value of p before k can be determined, because neither A_s, the area of steel reinforcement, nor bd, the area of the concrete, would be known at this stage. The ratio p depends upon the allowable stresses in the steel and concrete, and the value of n. The value of p must be such that the forces of concrete and steel are equal, so that when combined with a lever arm, their moments shall be equal and allow of the strengths of concrete and steel being simultaneously reached. The following formula gives the value of p.

$$p = \frac{\frac{1}{2}}{\frac{f_s}{f_c}\left(\frac{f_s}{nf_c} + 1\right)}$$

The value of f_s is 18,000 lbs., and the value, as already adopted, of f_c is 750 lbs. per square inch. The value of n is 15.

Substituting these values in the formula as

$$p = \frac{\frac{1}{2}}{\frac{18,000}{750}\left(\frac{18,000}{15 \times 750} + 1\right)} = 0{\cdot}008$$

Using this value of p in the formula for the value of k as

$$k = \sqrt{2 \times 0{\cdot}008 \times 15 + (0{\cdot}008 \times 15)^2 - 0{\cdot}008 \times 15}$$
$$= 0{\cdot}3843$$

The centre of gravity of the effective concrete fibres is $\frac{1}{3}$ k below the top of the beam.

$$\frac{1}{3}k = \frac{0{\cdot}3843}{3} = 0{\cdot}1281$$

The value of j, that is the distance from the centre of gravity of the concrete fibres to the centre of gravity of the steel reinforcement, is:—

$$j = 1 - \frac{k}{3} = 1{\cdot}000 - 0{\cdot}1281$$
$$= 0{\cdot}8719 \quad \text{Say } 0{\cdot}87$$

Having the N.A., the lever arm, j and p, it is possible to develop the formula for the moments of resistance of the concrete and the steel. Taking the moment of the concrete first: The concrete above the N.A., that is b $\times$ kd, will be available to resist compression. The layers in this area will have most value as resistance to compression at the top of the beam, but will diminish as the N.A. is approached until at the N.A. they will have no value. The triangle in the top of the beam having b as a base and the point O as a vertex, will represent the effective or proportionate area of the values of the layers in compression. The area of this triangle will be (see Fig. 21).

$$b \times \frac{kd}{2} = \frac{b\ k\ d}{2}$$

This area multiplied by f_c, the allowable stress per square inch on the concrete, will give the concrete force or

$$\frac{b\ k\ d}{2} \times f_c = \frac{f_c\ b\ k\ d}{2}$$

This force, multiplied by the lever arm jd, will be the moment of resistance M_c of the concrete, as

$$M_c = \frac{f_c\ b\ k\ d}{2} \times j\ d$$
$$= \frac{f_c\ k\ j\ b\ d^2}{2}$$

The moment of resistance of the steel can be developed as follows:—

$$\frac{A_s}{bd} = p$$

so that $\quad A_s = p\ b\ d.$

It will be remembered that A_s is the area of the steel and bd is the area of the concrete in the section. p expresses the ratio of b x d to A_s. p is, of course, determined early in any

calculations since it has to be known before the position of the neutral axis can be determined. It will, therefore, be clear that the area of the steel can be expressed in abstract form as p b d. This area, multiplied by the allowable stress per square inch for the steel, will give the steel force as

$$p\,b\,d \times f_s \text{ or } f_s\,p\,b\,d = \text{steel force}$$

This force, multiplied by j d, will be the moment of resistance of the steel as

$$M_s = f_s\,p\,b\,d \times j\,d = f_s\,p\,j\,b\,d^2$$

88. Example: Calculation of a Reinforced Concrete Beam. It will now be possible to determine the strength of a reinforced concrete beam. Assume that the load, span, and breadth on the beam be given as W = 20,600 lbs. The span is 16 ft. or 192 in., and the breadth of the beam is 10 in. As used in the formulæ, the allowable stress on the concrete will be 750 lbs. per square inch. The allowable stress on the steel will be 18,000 lbs. per square inch. $n = 15$, $p = 0{\cdot}008$, $k = 0{\cdot}385$, and $j = 0{\cdot}87$. It is required to find the depth.

Let M = the bending moment,

$$\text{then } M = B\,M = \frac{WL}{8} = \frac{20{,}600 \times 192}{8} = 494{,}400 \text{ in. lbs.}$$

Let M_c = moment of resistance of the concrete force,

$$\text{then } M_c = \frac{f_c k j b d^2}{2}$$

Therefore,

$$d = \sqrt{\frac{2 \times 494{,}400}{10 \times 750 \times 0{\cdot}385 \times 0{\cdot}87}} = 19{\cdot}8 \text{ in. Say 20 in.}$$

The area of steel required for the reinforcement will be

$$p = \frac{A_s}{bd}$$

Therefore, $A_s = pbd$.

Substituting values as

$$A_s = 0{\cdot}008 \times 10\text{in.} \times 20\text{in.} = 1{\cdot}6 \text{ square inches of steel reinforcement.}$$

Say 3 rods are to be used; then, $\frac{1{\cdot}6}{3} = 0{\cdot}533$ square inches area for one rod. $\frac{7}{8}$ in. rods have an area of 0·601 square

inches. This is more than is required, but will be used in this example.

NOTE: The beam would be made at least 21 in. deep to give covering for the reinforcing rods at the bottom.

89. Bond Stress. Reinforcing rods may slip or be pulled out of concrete by stresses due to shearing. The resistance of this kind of stress is called "Bond," and is brought about by the adhesion of the concrete to the steel, and also by shrinkage of the concrete. It will be obvious that the more the surface of the reinforcing rods, the more the adhesion and grip. The S.A.A. Code requires that the bond stress due to shrinkage shall not be more than ·04 of f'_c for plain rods, and not more than ·05 f'_c for deformed rods. The resistance to bond stress can be calculated as follows:—

Let V = the total shearing stress.
u = the bond stress in lbs. per square inch.
o = the perimeter or circumference of one rod.
Σ o = the total of the perimeters or circumferences of the rods if more than one.

$$\text{Then } u = \frac{V}{jd\Sigma o}$$

Since it is convenient to determine the sum of the perimeters of the rods when the total shear V, the maximum bond stress allowed, and jd, are known, the equation can be rewritten as

$$\Sigma o = \frac{V}{jd \times u}$$

Applying this to the beam in the previous example

$$V = \frac{W}{2} = \frac{20{,}600}{2} = 10{,}300 \text{ lbs.}$$

The maximum bond stress = 2,200 lbs. $\times$ 0·04 = 88 lbs.

Substituting these values in the equation as

$$\Sigma o = \frac{10{,}300}{0{\cdot}87 \times 20 \times 88} = 6{\cdot}7 \text{ ins.}$$

Circumferences of rods already decided upon for the beam are

Three $\frac{7}{8}$ in. diam. rods = 2·748 $\times$ 3 = 8·244 ins.

so that there will be more than enough to give bond.

It may be that the sum of the perimeters of the rods will not, in some cases, be sufficient to provide area to resist the

bond stress. It will then be necessary to provide anchorage for the ends of the longitudinal reinforcing rods. This anchorage is obtained by turning the ends of the rods through a bend of 180°. The radius of the bend should be 5d. d being the diameter of the reinforcing rod as shown in Fig. 22.

90. Diagonal Stresses in Concrete Beams. Fig. 23 shows what is likely to take place in a concrete beam owing to the diagonal tension due to vertical shearing stress V. It shows that a portion of the beam between the supports tends to break along diagonal planes and fall away.

If the cross section of an area of the beam be sufficient and the concrete comprising it be of good quality, the beam may be able, by the concrete alone, to resist the tensile diagonal stresses due to the vertical shear at any place. If, however, the concrete alone is insufficient to resist the stresses, the beam must be reinforced by what is called web reinforcement. Web reinforcement may be in the form of rods bent up or placed at right angles to the planes of likely fractures as at ac at A, Fig. 23, or the reinforcement may be in the form of vertical stirrups as at 1 2 3 B, Fig. 23, or inclined rods and stirrups may be conjointly used.

If inclined rods or stirrups be used, the vertical component of their resisting value must be at least equivalent to the vertical shear V, since their resistance must act against the direction of vertical shear. The inclined or vertical stirrup reinforcement must also be spaced sufficiently near to effectively cross all planes at 45°, otherwise an inclined fracture could happen between them. In Fig. 24, ac is a tensile stress in an inclined stirrup and bc the vertical component. θ is the angle between the stirrup and the axis at the beam. The area of the steel required in the stirrups and their spacing apart can be determined by the following formula:—

If A = area of rods or stirrups:—

t = allowable stress per square inch for steel stirrups = 14,000 lbs. per square inch.

θ = angle of inclined rods or stirrups with axis of the beam.

V′ = excess of total shear beyond what can be carried by the concrete alone.

S = spacing apart of rods or stirrups.

jd = effective depth of beam, or the lever arm of the moment.

$$\text{Then } S = \frac{A \times t \times jd \times \sin\theta}{V'}$$

It will now be possible to determine the resistance of shear stresses of the 20 in. × 10 in. beam, the safe distributed load for which was determined in Art. 88 *ante*.

Provided that the horizontal reinforcing rods are properly anchored with hooks as already described, the concrete may be allowed to take a vertical shear equal to 0·03 of f'_c. The ultimate strength of the concrete adopted for this beam is 2,200 lbs. This ultimate stress, namely

2,200 lbs. × 0·03 = 66 lbs. per square inch, as the allowable safe shear stress.

Usually, however, the adopted stress is not more than 40 lbs. per square inch. The area of the section of a beam is multiplied by the allowable stress, as

10 × 0·87 × 20 × 40 = 6,960 lbs. total allowable stress in shear.

It will be noted that the depth of the beam is taken as that of the lever arm. (This is the practice for this purpose.)

The amount, namely 6,960 lbs., is the resistance of concrete alone. The difference between this and the total shear stress at the support is what will have to be resisted by web reinforcement. The difference between the excess of shear over what can be taken by the concrete alone is called V′. The excess can be determined as follows:—

$$\frac{W}{2} = \frac{20{,}600}{2} = 10{,}300 \text{ lbs.}$$

$$V' = 10{,}300 - 6{,}960$$
$$= 3{,}440 \text{ lbs.}$$

Assuming that vertical stirrups are to be used, and that each stirrup is composed of rods ¼ in. in diameter. A circle ¼ in. in diameter has an area of 0·049 square inches. Since each stirrup has two legs, this area will be double as 0.049 × 2 = 0·098 square inches. Using the formula for vertical stirrups

$$s = \frac{A \times 14{,}000 \times j\,d \times \sin \theta}{V'}$$

When the stirrups are vertical the angle is, of course 90°. The sin of 90° is 1, so that for vertical stirrups the sin is omitted from the equation. Substituting values for the first foot of length of the beam

$$s = \frac{0{\cdot}098 \times 14{,}000 \times 0{\cdot}87 \times 20}{3{,}440}$$

$$= 6{\cdot}92 \text{ in.}$$

For the second foot and other points of the length the same formula would be used, but V′ would vary.

Stirrups spaced apart equal to, or more than, the effective depth d of a beam are obviously useless to prevent cracks occurring at an agle of 45° from the bottom to the top of the beam. Building regulations of most authorities require that the stirrups shall be spaced apart not more than some minimum amount of the effective depth of the beam. The building regulations of the Sydney Municipal Council require that stirrups, inclined or otherwise, shall be spaced apart not more than the $\frac{3}{8}$ths of the effective depth of the beam, if the shear stress exceeds 6 per cent. of the compression strength of the concrete. The stirrups may be spaced apart at intervals equal to $\frac{3}{4}$ of the effective depth, if the shear is less than 6 per cent. of the compression strength of concrete. Taking the minimum distance allowed by the Sydney Municipal Council as $\frac{3}{8}$ d, the spacing apart for this beam would be, taking 20 in. as the effective depth :—

$$\frac{20}{8} \times 3 = 7{\cdot}5 \text{ in.}$$

The spacing apart calculated for the first foot of the beam under consideration would be within this. In practice, however, the spacing would probably be made 6 in. One stirrup would be placed over the support, one at the end of the first foot, and one between. In the next three feet of span, the spacing apart could be 9 in.; thereafter stirrups would not be required.

TABLE XIA

Data for Reinforcing Steel Rods

Diameter, Inches	Circumference, Inches	Area, Square Inches
1/4	0·785	0·049
3/8	1·178	0·110
7/16	1·374	0·150
1/2	1·570	0·196
9/16	1·767	0·248
5/8	1·963	0·306
11/16	2·159	0·371
3/4	2·356	0·441
13/16	2·552	0·518
7/8	2·748	0·601
15/16	2·945	0·690
1"	3·141	0·785
1 1/16	3·337	0·886
1 1/8	3·534	0·994
1 3/16	3·730	1·107
1 1/4	3·926	1·227

91. Continuous Beams. Continuous beams are difficult to arrange in practice when using steel or timber, since the bear-

ings on intermediate supports must be absolutely level. There is, however, no such difficulty in the case of reinforced concrete construction. The concrete is poured integrally with the supports, so that all that is necessary is to secure that there be no settlement of the supporting columns.

The following table, taken from "Rivington," gives the reactions at the supports of continuous beams, having spans of from one up to six. Note that in drawing shearing diagrams, part of the reaction given by an intermediate support goes to make shear on one side of the support, and part on the other.

TABLE XIb

UNIFORMLY LOADED BEAMS CONTINUOUS OVER SEVERAL SUPPORTS

Table of Distribution of Loads

No. of Span	Number of Each Support, and Load Supported by it in Terms of W = Load on each Span						
	1st	2nd	3rd	4th	5th	6th	7th
1	$\frac{1}{2}$	$\frac{1}{2}$	..	..	..	..	..
2	$\frac{3}{8}$	$\frac{10}{8}$	$\frac{3}{8}$	..	..	..	..
3	$\frac{4}{10}$	$\frac{11}{10}$	$\frac{11}{10}$	$\frac{4}{10}$	..	..	..
4	$\frac{11}{28}$	$\frac{32}{28}$	$\frac{26}{28}$	$\frac{32}{28}$	$\frac{11}{28}$	..	..
5	$\frac{15}{38}$	$\frac{43}{38}$	$\frac{37}{38}$	$\frac{37}{38}$	$\frac{43}{38}$	$\frac{15}{38}$	..
6	$\frac{41}{104}$	$\frac{118}{104}$	$\frac{108}{104}$	$\frac{106}{104}$	$\frac{108}{104}$	$\frac{118}{104}$	$\frac{41}{104}$

Fig. 25 shows two cases of a beam continuous over two spans. The upper example marked A has its ends supported only at the end supports. The lower example marked B has its ends fixed or restricted at the outer supports. In the case of the beam with its outer ends supported only, bending will take place as shown. The portions marked "a" and "b" will bend downwards with a positive bending moment.

The portion marked c d above the central support would tend to bend upwards with a negative bending moment. In the case of the beam with its ends fixed or restricted, the portions a b will bend downwards due to positive moments, and the portions marked c d will bend upwards, due to negative bending moments. The point where the bending changes is called the point of contra flexure or inflection. The bending moments for continuous beams are arbitrarily fixed by the regulations of the various authorities. Fig. 26 shows the bending moment for a beam continuous over two spans. The negative bending moment over the central support is $\frac{WL}{8}$, the positive bending moments are each equal to $\frac{WL}{10}$

This is for a beam continuous over two spans and with its ends supported only. Fig. 27 shows the bending moment diagram for a beam continuous over three spans. The negative bending moments for the central supports are each equal to $\frac{WL}{10}$. The positive bending moment for the central span is $\frac{WL}{12}$, and the positive bending moment for the two outer spans are each $\frac{WL}{10}$.

If the ends of the beams be fixed or restricted a negative bending moment of from $\frac{WL}{16}$ to $\frac{WL}{24}$ is allowed over the end supports. This brings the outer turn of the curve down to make a negative bending moment and reduces the positive bending moment, as shown by Fig. 28.

The fact should be stressed that since the pouring of the concrete makes the beams and slabs continuous, it would be dangerous to neglect the calculations necessary to take into account this continuity. The stresses in continuous beams and slabs, as will have been gathered from the foregoing descriptions, are altogether different from those in simple beams, and it should be clear that it would be very dangerous to calculate continuous beams and slabs as simple beams and slabs.

Continuous beams are designed using the same formulae as described in Arts. 88-90 *ante,* but care must be taken to use the correct B.M. formula.

92. Reinforced Concrete Floor Slab. As an example, take a slab which measures 10 ft. in one direction and 11 ft. in the other. The first step is to calculate the dead and live load per square foot. The dead load of the slab can, of course, only be estimated since its thickness is not yet known. As a general rule slabs weigh, per square foot, 12 lbs. per inch of thickness, so that assuming a thickness 4 in., the weight of the slab will be $12 \times 4 = 48$ lbs. per square foot. Assume that the slab is covered with topping which weighs 10 lbs. per square foot. Also assume that the floor is for an office building which would require an allowance for live load of 100 lbs. per square foot. Then

Live load on slab	=	100 lbs. per square foot
Dead load on slab	=	48 lbs. per square foot
Dead load of topping	=	10 lbs. per square foot
Total	=	158 lbs. per square foot.

In designing a slab it is usual to take a strip 12 in. wide and to design the strip as a beam 12 in. wide over the given span.

The load on a rectangular slab is assumed to be carried in the short direction. In this case the short direction is 10 ft. or 120 ins.

The bending moment $= \dfrac{WL}{12}$, since the slab will be continuous over supports.

Then the bending moment =

$$\frac{WL}{12} = \frac{1{,}580 \times 120}{12} = 15{,}800 \text{ inch lbs.}$$

Using the formula for the determination of the depth as

$$d = \sqrt{\frac{2 \times 15{,}800}{700 \times 0{\cdot}3684 \times 0{\cdot}877 \times 12}} = 3{\cdot}29 \text{ sq. ins.}$$

Allowing that the steel will require 1 in. of covering, the slab will be $4\frac{1}{2}$ in. thick. (NOTE: Thickness of topping must be added to this depth.)

$$A_s = p\ b\ d = 0{\cdot}008 \times 12 \times 3{\cdot}29 = 0{\cdot}316 \text{ inches.}$$

Try 3 rods. Then each rod $= \dfrac{0{\cdot}316}{3} = 0{\cdot}1053$ square inches in cross section.

A $\frac{3}{8}$ in. rod has an area of 0·110 square inches. This is a little in excess but will be adopted. The rods would be spaced at 4 in. centre to centre.

It has been assumed that the load on the slab is to be carried in one direction only, and that is the short direction. This gives a result which will be on the safe side. Some economy can be effected by taking into consideration the fact that since the slab is supported on four sides it is possible to assume the load as being resisted in two directions. The S.A.A. Code allows, when two-way reinforcement is used, to have half the live and dead load resisted in each direction, when the slab is square in plan. If the slab be rectangular in plan, the length being L and the breadth b, the portion of the load to be assumed as being supported by the slab in the short direction may be $\frac{L}{b} - 0{\cdot}5$, multiplied by the total load. The remainder of the load to be carried by the slab in the long direction.

When one-way reinforcement is adopted, as in the case described, it is necessary to put what are called temperature rods at right angles to the reinforcing rods. These rods are to prevent cracks due to temperature changes, and should be about ⅜ in. diameter spaced 24 in. apart.

The reinforcing rods will require to be bent up over supports, to resist negative bending moment, which, although not calculated for a slab, is there all the same, and must be taken into consideration. The usual method is to bend up alternate rods.

93. Reinforced Concrete Columns. Reinforced concrete columns are formed by embedding vertical steel rods, four or more in number, in the concrete, as shown by Figs. 29 and 29A, which show square columns having four vertical steel reinforcing rods. In Fig. 30 is shown a square or rectangular column having eight vertical reinforcing rods. Fig. 31 is a section of a circular column having eight vertical rods. In the case of reinforcing being done in the way shown by Fig. 31, the rods are arranged in a circle, the exterior of the column being either a circle or a polygon. In the case of a square or rectangular column, the rods are tied together by steel ties or laterals, and, in the case of a circular arrangement, they are either bound with spirals or hoops. The laterals or hoops are required to prevent the rods buckling. The concrete within the rods prevents any tendency of the rods to bend inwards under stress, but there is insufficient concrete to prevent an outward bending, which has to be resisted by laterals or hoops. Fig. 29B shows the tendency of rods to buckle under compression.

Building regulations generally limit the length or height of a column to not more than fifteen times the least cross sectional dimension. That is to say, by the regulations, a column having a cross section of 12 in. $\times$ 14 in. cannot be more than 15 ft. high, that is fifteen times the least dimension, which is 12 ins.

The notation used in the design of concrete columns is the same as used for beams and slabs. There are, however, some symbols which should be mentioned. One is the symbol of the height which is denoted by H. The height H is the unsupported length of the column. The area of the vertical reinforcing rods, which is an important feature, as in the case of beams, is known by the symbol A_s. Fig. 32 shows a column, with beams of uneven depth running into it. The height H is the distance from floor level to underside of beam. In this case the beams being uneven in depth, the height H^1 is as shown to the underside of the shallowest beam. The area A is that of the concrete which lies inside the external surface of the vertical reinforcing rods, and minus the area of the steel rods. This area is the effective area. The load is generally denoted by P.

The safe axial load P to be taken by a concrete column is the compression resistance of the effective concrete, plus the compression resistance of the steel. This is expressed by the following equation.

$P = A\ f_c + A_s'f_s$ in which A is the area of effective concrete and A_s is the area of the steel. In this form, however, the equation is of little value, since the relative shortenings of the steel and concrete and the percentage of steel have to be taken into consideration when designing. The following reasoning will result in an equation involving all the factors. The symbol A_s, the area of steel, may be written as a percentage or a ratio of the area of concrete, as p A, so that the ratio of concrete and steel, multiplied by f_c will give the safe resistance of the concrete as $(A - p\ A)\ f_c$.

The resistance of the steel reinforcement will be n times f_c, since in order to secure equality in the compression of the steel and concrete and corresponding shortening, the stress on the steel, as compared with the stress on the concrete, must be in the ratio of the moduli of elasticity of the two materials. Then the stress on the steel can be further represented by multiplying the ratio n of the elasticities by the allowable stress on the concrete, as n f_c, so that the area of the steel multiplied by the stress n f_c will give the resistance of the

steel as $p\ A\ n\ f_c$. Combining these will give an equation more useful in form as

$$P = (A - p\ A)\ f_c + p\ A\ n\ f_c.$$

Taking out the common factor $A\ f_c$, the equation can be written as

$$P = f_c\ A\ (1 - p + pn),$$

or by a further arrangement—

$$P = f_c\ A\ \Big(1 + p\ (n - 1)\Big).$$

An example of the application of the formula in the design of a reinforced concrete column, is given by the following:—

A column 15 ft. high and 16 in. $\times$ 16 in. outside cross section dimensions is reinforced with four longitudinal rods. The rods are to be kept back on the external surfaces, so that the area within the reinforcing rods E F G H will be 12 in. $\times$ 12 in. (See Fig. 29.). Consequently

$$\begin{aligned} A &= 12 \text{ in.} \times 12 \text{ in.} = 144 \text{ square inches} \\ \text{take}\quad p &= 0{\cdot}02 = 2 \text{ per cent. of reinforcement} \\ n &= 15 \\ f_c &= 700 \text{ lbs. per square inch.} \end{aligned}$$

Formula as given before is

$$P = f_c\ A\ \Big(1 + p\ (n - 1)\Big).$$

Substituting values in the above equation as

$$\begin{aligned} & 700 \times 144\ \Big(1 + 0{\cdot}02\ (15 - 1)\Big) \\ &= 700 \times 144\ \Big(1 - 0{\cdot}02\ (14)\Big) \\ &= 700 \times 144\ \Big(\ 1 + 0{\cdot}28\Big) \\ &= 700 \times 144 \times 1{\cdot}28 \\ &= 129{,}024 \text{ lbs.} \\ &= 57{\cdot}6 \text{ tons.} \end{aligned}$$

A_s equals the area of steel, which is to be 2 per cent. of the effective area of concrete, that is to say 2 per cent. of 144 square inches. Worked out, this is

$$\frac{144}{100} \times 2 = 2{\cdot}88 \text{ square inches.}$$

Assuming there are four rods, so that $\frac{2 \cdot 88}{4} = \cdot 72$ square inches as the area of each rod. 1 in. rods have an area of 0·7854 square inches. This area will be a little in excess, but would be used.

The ties for laterals could be spaced apart fifteen times the diameter of one of the reinforcing rods, but must not be more than 12 in. apart in any case. According to the diameter proportion, since the rods are 1 in. in diameter, the spacing apart would be 15 in., but the maximum spacing allows only 12, so that 12 in. apart would be the spacing.

An example of the method of determining the safe load of a reinforced column, circular in cross section, and reinforced with eight longitudinal rods, is given below.

A circular column 16 ft. high, and 20 in. in diameter from centre to centre of the reinforcing rods, and 24 in. external diameter, is to be reinforced with 8 longitudinal rods, each 1 in. in diameter.

f_c is to be taken as 600 lbs.

$n = 15$

$A = d^2 \times 0 \cdot 7854 = 20 \times 20 \times 0 \cdot 7854 = 314 \cdot 16$ sq. in.

Since diameter of rods = 1 in., the area of each will be 0·7854 square inches. There being 8 rods, the total area of steel

$$A_s = 0 \cdot 7854 \times 8 = 6 \cdot 28 \text{ sq. ins.}$$

$$p = \frac{A_s}{A} = \frac{6 \cdot 28}{314 \cdot 16} = 0 \cdot 02, \text{ or } 2 \text{ per cent.}$$

$$P = f_c A \left(1 + p\ (n - 1)\right).$$

Substituting values as

$$\begin{aligned} P &= 600 \times 314 \cdot 16 \left(1 + 0 \cdot 02\ (15 - 1)\right) \\ &= 600 \times 314 \cdot 16 \times 1 \cdot 28 \\ &= 241{,}275 \text{ lbs.} \\ &= 107 \cdot 712 \text{ tons.} \end{aligned}$$

The rods can be tied either with spiral or with horizontal individual hoops. In the event of the spiral tie, the total volume of metal spiral should be 1 per cent. of the total volume of any given length of the column. In the case of individual ties, the diameter of the rings should be not less

than $\frac{1}{4}$ in., and spaced at a distance apart of not more than fifteen times the diameter of one of the longitudinal reinforcing rods. The rings would be spaced 12 in. apart, since this is the maximum spacing, although, according to the general rule, they could be fifteen times the diameter of one of the rods apart, which would be 15 in.

2 per cent. of steel reinforcement is an economical ratio. f_c f_s are also generally within limits to allow of n being 15, so that p is generally 0·02. Such being the case, the term enclosed in large brackets, of the equation given above, works out as a constant quantity, namely 1·28. The equation

$$P = f_c \, A \left(1 + p \, (n - 1)\right)$$

can, therefore, become

$$P = f_c \, A \times 1{\cdot}28.$$

Using the equation in this form, reduces the calculations as the following example will show. It is required to find the safe load for a reinforced concrete column 19 in. × 19 in. in cross section. In this case, the effective area, or the core, will be 15 in. × 15 in. = 225 square inches.

$$\begin{aligned} P &= 600 \times A \times 1{\cdot}28 \\ P &= 600 \times 225 \times 1{\cdot}28 \\ &= 172{,}800 \text{ lbs.} \end{aligned}$$

The steel will be 2 per cent. of $A = \dfrac{225}{100} \times 2 = 4{\cdot}5$ sq. in.

If there be four rods, the area of each will be equal to

$$\frac{4{\cdot}5}{4} = 1{\cdot}125 \text{ square inches.}$$

$1\frac{1}{4}$ in. rods have an area of 1·22 square inches. If there be eight rods, then the area of each will be

$$\frac{4{\cdot}5}{8} = 0{\cdot}5625 \text{ square inches.}$$

$\frac{7}{8}$ in. rods have an area of 0·601 square inches, and eight of these would do very well.

CHAPTER IV

BRICKS

94. **Clay,** from which bricks are made, is one of the products of the decomposition of rocks which contain aluminous minerals, such as granite, gneiss, mica, slate, and most kinds of basalt and trachyte. Rain water, acids in the atmosphere, sea waves, and such other agents of denudation are always causing decomposition of rocks, and the particles disturbed are carried off in suspension by the water, and finally deposited either on the sea-beds, in the estuaries of rivers, or on the banks of the latter during their overflow.

The immense beds of clay accessible at the present time have been accumulated by such means, and, owing to geological disturbances and adjustments, have been elevated to positions above the level of the sea, lake, or river. Generally, these beds are of a yellow to reddish colour, and loose formation at top, with a tendency to white and compactness as the depth increases, while at a great depth below the surface they become a bluish grey compact shale. The reddish colour at the surface is due to the iron contained in the clay becoming oxidised through the action of surface water and atmospheric influence. There are, of course, cases where iron is practically absent, and hence a white colour at the surface.

95. **Pure Clay,** or kaolin, as it is called, is a hydrated silicate of alumina; and, of the constituents of the rocks, particularised above, the one that yields this pure clay is feldspar, which is a silicate of alumina plus a small quantity of alkalis, which are bleached out during weathering or decomposition. Clay is, however, rarely found in a pure state—indeed, only in such cases where the felspar has been decomposed *in situ*, for, during the translation by water the particles become associated with impurities such as lime, magnesia, iron oxide, organic matter, etc. Clay, therefore, is a material composed mainly of silica and alumina, with water for hydration, together with small proportions of metallic oxides, lime, alkalis, etc.

96. **Table XII** gives the chemical composition or samples of some Australian clays, and also of pure kaolin and Stourbridge fire clay.

97. A great deal depends upon the relative proper proportions of the essential constituents, and on the absence of more than a certain maximum amount of those which have an injurious tendency. Hence it will not be going outside the legitimate scope of these articles to enter into some explanation as to the character and functions of each of the various constituents.

98. The essential constituents are, as before stated, silica and alumina. Lime, magnesia, iron oxide, and alkalis are, however, generally met with, and are under certain conditions useful, as will be explained later on; but, in excess, they are injurious.

99. Iron Pyrites, common salt, and organic substances are frequently found in brick clays, and are all injurious in direct proportion to the quantities which may be present.

100. Silica (oxide of silicon) is essentially an acid oxide infusible unless in the very highest temperature, and occurs in three forms: Crystalline, or quartz; amorphous or flint; and in combination with other bodies. It exists in a state of combination with alumina as *Silicate of Alumina* in all clays; and in most, also, in a free state, as flinty quartzose grains known as sand.

101. Alumina (oxide of aluminium) is practically infusible. Like silica, it occurs in great abundance, and forms an essential constituent of brick clay. The paste formed by mixing it with water is very plastic, and shrinks very much if dried and heated.

102. The Combination of Silica and Alumina forms the silicate of alumina, which, when hydrated, is the pure clay or kaolin. This silicate of alumina is very refractory, and becomes very hard when subjected to heat; but it shrinks very much, and consequently bricks made from it are twisted and warped out of shape. An excess of alumina only increases the shrinking and warping tendencies. On the other hand, as the quality of silica is increased so is the liability to shrink reduced, while the refractory properties are in no way interfered with. Whatever quality there may be, free, and in excess, will be in the form of quartzose or flinty sand, and the more there is the more brittle will be the substance of the brick. It follows, then, that silicious sand may be added to "strong" or pure clay to prevent the warping and twisting due to shrinkage, so that a shapely brick may be produced; but, at the same time, it must be remembered that the brick will be of a crumbling and unstable nature, because the heat has no power to even

partially melt the grains of sand and produce adhesion throughout the mass. A brick should have the constituent bodies consolidated into a partially vitrified mass, so that, while being shapely, it will be thoroughly hard and compact.

103. **The most powerful basic bodies,** such as alkalis and oxides of iron, combine readily with silica, and the silicates so formed when exposed to high temperatures become vitreous. Silica also combines with lime, and under the action of great heat vitrification takes place, but not to such a great extent as in the case of the bases before mentioned. Alkalis, oxides of iron, and lime are therefore useful as fluxes to produce the vitrification necessary for a hard brick, and, when not present naturally, one or the other may be added. There is, of course, a limit to the quantity, because too much of these fluxes produce the very worst results, for, instead of bringing about a partial vitrification, an excess causes the whole mass to melt, run, and become shapeless.

104. **Owing** to the number and varying proportions of the constituents of ordinary brick clays, many extremely complex compounds are formed. In the articles immediately preceding this a pure or "strong" clay was described, and the author pointed out that, though very refractory, it was liable to warp and twist, and that this troublesome tendency could be overcome by providing an excess of silica in the form of sand — an improvement which, however, was in a great measure counterbalanced by the disadvantages attending the friable and crumbling brick which would result. But this defect could, it was stated, be avoided by providing also for the presence of some materials which would render the silica and alumina more fusible, and so partially melt and form into a semi-vitreous mass. So far so good, but it is by the presence of these necessary additional bodies, together with impurities, which practically are impossible of avoidance, that serious complexity occurs.

105. **As** before stated, the silica is ready to combine with the basic bodies such as potash, soda, the oxides of iron, lime, magnesia, and alumina. Moreover, some of the oxides of the earthy metals are among themselves likely to combine. Compounds are consequently formed, the exact behaviour of which, under the influence of heat, it is not an easy matter to determine, and cannot very well be entered into here. A general notice of some of the main points connected with these compounds is, however, unavoidable.

106. **A Compound** of silica with one base is much more difficult to fuse than a compound of silica and two or more

TABLE XII
Chemical Analysis of Brick Clays

No.	Description of Specimen	Locality	Moisture at 100° C.	Combined Water	Silica	Alumina	Ferric Oxide	Ferrus Oxide	Manganous Oxide	Metallic Copper	Lime	Magnesia	Potash	Soda	Phosphoric Acid	Sulphuric Acid	Titanic Acid	Organic Matter	
1	White Clay	Dubbo, N.S.W.	1·09	13·38	45·27	39·05	1·80	—	—	—	—	·22	·32	—	trace	—	trace	—	100·41
2	White Clay	Mudgee, N.S.W.	·34	3·71	73·28	18·00	5·4	—	—	—	·37	·33	·07	3·73	—	—	—	trace	100·37
3	White Clay	Milton, N.S.W.	6·85	11·35	45·79	34·54	·90	—	—	—	·31	trace	·65	trace	trace	—	—	trace	100·39
4	Hard Black Clay	Bourke, N.S.W.	4·01	8·29	52·52	25·79	7·48	—	trace	—	·68	·54	·58	—	trace	—	—	trace	99·89
5	Soapy Clay	Parkes, N.S.W.	7·65	4·62	50·68	18·71	12·51	—	trace	—	·52	2·28	1·34		trace	1·69	—	—	100·00
6	Dark Grey Clay with plant impressions	Richmond River, N.S.W.	3·05	4·63	63·02	20·96	2·94	—	—	—	1·32	1·06	2·90	·44	·04	trace	—	—	100·36
7	Shale	Mount Pleasant Coal Mine, N.S.W.	1·48	4·61	68·28	21·29	·87	—	—	—	·30	·70	1·86	·31	—	—	trace	trace	99·70
8	Dark Green and Purple Grey Clay Shale.	Sydney, N.S.W.	3·38	5·32	56·28	24·21	7·34	—	—	·08	1·10	2·36	—	—	—	—	—	—	100·07
9	Clay	Lilydale, Victoria	Water 4·81		67·92	21·72	3·72	—	—	—	·62	·66	—	—	—	—	unestimated ·55		100·00
10	Black Clay found under coal measures	Stourbridge, England	Water and Organic Matter 10·30		63·30	23·30	—	1·80	—	—	·73	—	—	—	—	—	—	—	99·43
11	Pure Kaolin	England	Water 13·90		46·30	39·8	—	—	—	—	—	—	—	—	—	—	—	—	100·00

Nos. 1, 2, 3, 4, 5, 6, 7, and 8, from Reports Department of Mines, N.S.W. No. 9 from Reports Department Mines, Victoria. No. 10 from p. 122 "Notes on Building Construction" (Rivington). No. 11 from p. 110, Vol. 68 "Builder."

bases. That is to say, a double silicate of lime and alumina is more easily fused than silicate of alumina; and so on. Again, the bases differ as to their power of causing fusion, as follows:—

> Commencing with the most powerful, and proceeding in order: Alkalis, oxides of iron, lime, magnesia, and alumina. Moreover, the power to cause fusion of the fluxing bases, such as alkalis, oxides of iron, and lime varies as the proportions of the other oxides differ. For instance, oxide of iron causes fusion at a comparatively low temperature if the silica and alumina be in equal proportions.

107. Impurities of a useless and more or less dangerous character which are commonly found in brick clays are iron pyrites, pebbles of carbonate of lime, organic matter, and common salt.

108. Iron Pyrites (*Bisulphide of Iron*) is often found in clay —mostly in shale. This substance is very hard, and has a brassy-yellow colour. It should be removed from the clay, for if left it is very likely that only partial decomposition will take place during the burning process, and oxide of iron and basic sulphides of iron remain, so that afterwards, when exposed to air and moisture, an extension of oxidation takes place, sulphides of iron are formed, and possibly also the sulphur will attack the lime, forming sulphate of lime. Oxidation causes an increase of bulk, the sulphates in forming crystallise, and these actions split the brick and disintegrate it.

109. Limestone Pebbles are a fruitful cause of trouble if allowed to remain in the clay, because during burning the CO_2 is expelled, and the pebble is turned into a lump of *quicklime*, which will slake directly the brick is subjected to the action of moisture, and splitting will result.

110. Organic Matter if not completely destroyed by the heat, causes, in many cases, the exudation of compounds of a soluble nature which discolour and disfigure the surface of the bricks. The presence of organic matter is very objectionable and should be avoided.

111. Common Salt is generally found in more or less quantity in clays of marine deposition. It is a very objectionable impurity, possessing, as it does, the power of fluxing in the highest degree, and it is on that account impossible to burn clay containing it into hard bricks.

112. The proportions of the various constituents in any kind

of clay are, of course, shown by chemical analysis, but the information thus obtained is not alone sufficient for all practical purposes, because the analysis does not clearly show the kind and extent of the combinations formed by the different bodies. As an illustration of this, take the case of silica. A chemical analysis will show the exact quantity present, but it does not show how much is in the state of sand, and what quantity is in combination with other constituents. As explained in connection with cement analysis, an experienced chemist may be able to make a fairly reliable calculation as to the kind and extent of the combination by an inspection of the analysis; but in the case of clays, at any rate, it has been so far the rule, that in addition to the chemical analysis, a careful microscopic examination, together with trials of the clay, has been necessary to arrive at a just estimate of the value of a clay for making and burning into a shapely and hard brick.

113. Concerning the Analysis, it may in a general way be taken that for good ordinary bricks the silica may range from 60 to 70 per cent., and the alumina from 18 to 24 per cent., the balance of the other constituents in no case being over 16 per cent. The silicates should, however, not be over 4 per cent. of the whole clay. In the Table XII, examples of English fire clay and kaolin (Nos. 10 and 11) have been inserted to form a basis of comparison with some of the Australian clays. The representative range of the Australian clays is not as satisfactory as it might be, owing to the difficulty to get records of tests; but those available, and inserted in the table, have been made by experienced and able analysts in the official service of the States indicated, and, so far as they go, may be taken as reliable. Nos. 1 and 3 are very "strong" clays, and would be liable to shrink; obviously sand would be needed in making bricks from these clays. No. 2 was experimented with, and stood a very high temperature successfully, as would be expected from the large amount of silica and the small quantity of fusion-causing materials. Examples 4, 5, and 8 contain too much iron oxide to allow of being burnt into good bricks. No. 5 is especially poor, and is inserted to illustrate a really bad clay. A trial was made with No. 6, with the result that a fairly hard, reddish-coloured brick was obtained; it, however, contains about the limit of the constituents other than silica and alumina.

114. Colour of Bricks. The impurities contained in the brick clay have an important influence on the colour when burnt, but the conditions surrounding the burning also have much to do with the appearance of the finished brick, and to produce any particular colour the method of burning, as well as the

constitution of the clay, must be taken into consideration. It is, unfortunately, not the general rule with Australian brick-makers to scientifically deal with the question of colour, for most of them are content to proceed by rule of thumb methods which are the result of their local experience; and anybody who has had to do with obtaining supplies of bricks of any particular tint knows how uncertain and unsatisfactory these methods are.

115. Bricks may be produced ranging from white to black, and from cream, buff, brown, all kinds of red, to dark blue and purple; and it should be possible, with the aid of careful examination of the clays at hand and judicious mixing, to produce any number of bricks of any particular tint of these colours.

116. Iron Oxide has a great deal to do with the colour, for it is very seldom altogether absent from brick clays, and by its influence principally, cream, yellow, orange, light red to dark red, dark blue and even black are produced. Lime, in conjunction with iron has also an important part to fulfil, and where naturally not present is often added; but care is always taken that it is supplied in a very fine state to prevent trouble as explained in Article 109 *ante.*

117. Description of Colouring Constituents. A necessarily brief description of the constitution of the clays to produce white and the various coloured bricks is given below:—

(a) White: Clay containing iron and small quantities of other impurities, with a fair amount of lime added to it, will burn into white bricks if subjected to a high temperature, which causes the formation of a ferri-alumina-calcic silicate, in which combination the red colour of the iron oxide disappears. The pure clay or kaolin will burn into a white brick, but, as before pointed out, it is liable to warp and twist in the kiln. The method adopted to overcome the warping is as follows: A certain large proportion of the clay is mixed up and burnt into ballast, after which it is ground up and added to the raw clay. The whole is then worked up, moulded into bricks, and finally burnt.

(b) Cream: Clay containing a fair amount of iron oxide, with lime added, but not burnt at such high temperature as in the case of white bricks.

(c) Yellow: Clay with a little lime, and fairly large amount of iron oxide, fired at a moderate temperature.

(d) Brown: Clay containing 3 to 4 per cent. of magnesia.

(e) Light Red to Full Red and Dark Red: Clay containing oxide of iron, with lime altogether, or practically, absent, the degree of red increasing as the temperature is raised.

(f) Dark Blue and almost Black: Manganese in presence of iron oxide, or iron oxide present to the extent of more than 10 per cent., gives a dark purple blue when fired at a high temperature.

(g) Light Blue: Pure clay with phosphates of lime and alum added.

The fancy coloured bricks are burnt in close kilns, and good qualities of attractive colour are got from open kilns; but the common brick, from the now almost generally used patent continuous kiln on the Hoffman principle, is of a pale and uninviting colour, due, it may be suggested, either to the bleaching action of the aciduous fumes in the close chambers, or to the possibility that the oxygen admitted is sufficient only for the needs of combustion, so that oxidation of the iron does not take place, for it may be noted as a significant fact that bricks of the same constitution put in the old kiln burn a strong red colour.

118. From the foregoing it will be seen that the impurities, such as lime and the metallic oxides, which are contained in the clay, are the cause of the colour of the bricks when burnt, but it may be noted that, except in some cases, they effectually produce the desired colour without requiring to be present in sufficiently large quantity to prevent a sound and durable brick being produced. The production of a light cherry-red colour is a case in point, however, where the colour requirements prevent a very hard brick being made, for the iron has to be present in fairly large quantity and the temperature of burning cannot be high, consequently a hard brick is impossible.

119. Enamelled Bricks. It is the custom to sometimes use white enamelled bricks for such purposes as the facing of walls of ill-lighted rooms, like cellars, and for walls of light areas, to increase their effectiveness, as well as for lavatories and such other places, where cleanliness in reality, as well as in appearance, is a matter of importance. White enamelled bricks are not, however, the only kind used, for in external brickwork of an ornamental character enamelled bricks of various colours are often used. The glazing, or enamelling on the bricks is produced in much the same manner as that on pottery—by

immersing the faces to be glazed in a glazing composition which is in a liquid form, and then reheating them until the composition fuses and forms a glassy surface. There are many kinds of glaze compositions, but the following (see Table XIII), by Mr. W. D. Clark, will be found as good as any, provided that judgment and care are exercised in their use. It may be mentioned that the bricks, which, of course, are of first-class quality, are burnt in the ordinary way before applying the glaze.

120. Brick-making. The production of bricks may be carried on with a very small and unpretentious plant—a pick and shovel, rough-made moulding table, moulding tools, drying shed, and an old-fashioned open kiln; but in populous districts, where a large amount of building work goes on, the plant, consisting of building machinery and patent kilns generally

TABLE XIII

Showing Composition of Glaze for Enamelling Bricks.

In each case the constituents to be taken together in a retort and calcined, then reduced to powder and mixed with water to the constituency of cream. To be applied by immersian therein or with a brush.

CONSTITUENTS AND PARTS BY WEIGHT

Finished Colour of Enamel	Feldspar	Flint or Quartz	Paris White	Oxide of Zinc	Boracic Acid	Kaolin	Black Oxide of Manganese	Black Oxide of Cobalt	Oxide of Uranium	Brandon Mineral Paint	Potter's Blue	Oxide of Copper	Lime	Sub. Oxide of Copper
White	80	70	65	50	50	12	—	—	—	—	—	—	—	—
Black	80	70	65	50	52	12	2	1	—	—	—	—	—	—
Blue	80	70	65	50	52	12	—	2	—	—	—	—	—	—
Yellow	80	70	65	50	52	12	—	—	2	—	—	—	—	—
Drab	80	70	65	50	55	12	—	—	—	6	1	—	—	—
Green	80	70	65	50	52½	16	—	—	—	—	—	2½	—	—
Red	80	70	65	50	52½	8	—	—	—	—	—	—	—	2½

Compiled from text, page 78, "Bricks, Tiles, and Terra Cotta" (Davis).

represents a capital outlay of many thousands of pounds, because in the case of brick-making, as in almost everything else, the introduction of machinery, and the results of invention, have made a great change in the methods of production, so that the old-time style of making by hand is gradually disappearing, and in the cities and large towns hardly anything else but machine-made bricks are supplied. Before passing on, it may, however, be noted that amongst builders of conservative tendencies there is the constant complaint that the bricks made by machinery at the present time are not nearly so good as those made in the old days by the hand process; but there is nothing to support this contention, as the evidence afforded by comparative tests shows that the bricks now made by

machinery at many of the establishments have for all-round qualities never been equalled by hand-made bricks.

121. The Methods of manufacturing bricks may be classified under two heads, viz.:—

(1) Wet clay, or plastic process.
(2) Dry clay process.

122. Wet Clay is, of course, used when bricks are made by hand-power, but machines for making bricks with wet clay preceded those on the dry-clay system, and are still extensively used, even in brickworks which are conducted on a large scale.

The manufacture of bricks by hand-power alone is, as pointed out before, almost entirely a thing of the past; but it is impossible to pass on to the description of the modern methods of machinery without briefly dealing with the old-fashioned way of making bricks, for, under certain circumstances at the present time—as, for instance, away out in the "back-blocks"—it is only necessary to make on a very small scale, and machinery is unnecessary.

123. Bricks Made by Hand. The clay after being excavated is spread out and allowed to remain exposed to the disintegrating effects of the weather. By this means pebbles of limestone and iron pyrites are decomposed. It is next turned over and over, and well worked until it is in the condition of a plastic mass. The sand, which is largely used when making bricks by hand, is added during the latter process. When properly tempered and ready for being made into bricks, it is conveyed in lumps to the moulder's table, where it is received by the assistant, generally a youth, who cuts off a portion, about sufficient to make a brick, which portion he rolls and works up and passes to the moulder. The mould is a wooden box or frame without top or bottom, 10 in. long by 5 in. wide, and $4\frac{3}{8}$ in. deep. A piece of wood about one inch thick, and of a size to form a bottom for the mould, is nailed to the table. On this piece of wood or "stock" as it is called, is fixed another but much smaller piece, and which is pyramidical in form. This projection forms the indent known as the "frog" on the bottom face of the brick. To make a brick, the mould is dusted with sand, and placed on the stock, and the portion of clay received from the assistant is pressed by the moulder into it, so that the clay fills every part. The superfluous clay is then struck off with a wooden lath and the mould is lifted up, and the brick deposited from it on to a thin piece of wood called a "pallet board," on which the brick is conveyed to the "off-bearing" barrow. The barrow, when full, is wheeled to the drying sheds, where the bricks are stacked until dry enough to

be put in the kiln and burned. The drying of the bricks lasts from two days to a week, according to the condition of the weather.

Tempering by hand is a very primitive method, and a pugmill is almost always used for grinding and mixing clay. A pugmill is a machine consisting mainly of an upright shaft, armed with knives, which revolves in a hollow cylinder containing the clay.

124. Plastic Process by Machinery. The clay is put through a grinding machine, the rollers of which reduce all lumps and pebbles. From the grinding machine it is run into a pugmill, wherein it is mixed and kneaded. The shaft of the pugmill is fitted with a screw-like arrangement which forces the kneaded clay out through an opening at the end opposite to that where it entered. The opening is rectangular in shape, the size of the rectangle being about 10 in. x 5 in. The clay, therefore, emerges in a continuous band 10 in. x 5 in. in cross section, and is directed on to a metal table. When about sufficient to make 12 bricks has passed on to the table, a cut is made across it to sever it from the other part of the band. The section on the table is then made to pass through a frame containing 13 vertical wires $3\frac{3}{8}$ in. apart, which cut the band into bricks. The bricks are then removed in barrows, and stacked to dry in the same manner as if they were hand-made. The whole of the machinery is driven by steam-power, which is so contrived as to cause all the movements of the wire cutting of the clay band into bricks, as described. The bricks so made are rough on the two surfaces formed by the cutting of the wires, but they are really good bricks when well burnt. For important work, where appearance is of consequence, the bricks are afterwards pressed in a pressing machine, generally worked by hand, which forms good faces and sharp edges.

125. The following is a description in a general way of the process of making bricks with dry clay:—

The clay, after being excavated, is roughly mixed and put into trollies, which are hauled up an inclined railway, by means of a cable gear, to the building containing the grinding and moulding machinery. Each trolly is fitted with a collapsible bottom, which is released when above the grinding machine, and the clay is deposited into a chute that conveys it to the pan in which it is ground. This pan, which is continually and horizontally revolving, is circular in plan and of considerable diameter, but not very deep. A couple of large rollers, somewhat like grindstones in form, but composed of cast-iron, revolve with a vertical circular motion in the pan, and by their weight crush and reduce the clay to powder.

When so reduced the clay passes out through small holes, of which there are a great number in the bottom of the pan, and into a fixed pan called a "saucer," just a little larger than the revolving pan, from which it is conveyed in little buckets attached to an endless and continually moving band to a platform above the moulding machine, from which it is fed by a chute into the moulding machine.

The machine used for moulding, or, more properly speaking, pressing, bricks on the dry clay system consists of two main movements as follows:—

(1) An arrangement for filling the moulds with the prepared clay, as delivered by the chute from above.

(2) An arrangement for compressing with great force the clay into the mould, and so forming the brick.

The movement for filling the clay into the mould also at the same time pushes the last pressed brick from the mould on to a table clear of the pressing heads. Most of the machines in use make two bricks at a time, but some kinds make three bricks at once.

The machine is driven by the power from the power unit conveyed by belting, and the circular motion so obtained is transformed into the movements by means of cranks and cams. There are, of course, variations in detail in the machines by different makes, but the foregoing will, it is hoped, give a good idea of the principle of a dry-clay pressing machine.

The bricks, as they are pushed from the moulds, are removed in barrows directly to the kilns and stacked therein, and are in a very short time burnt. A very short period elapses from the time the clay is filled into the trollies in the pit, until it is stacked in the kiln in the form of bricks ready for burning; and in this particular the dry-clay process presents a marked contrast to the wet-clay process, for, in the case of the latter, the bricks have to be dried before being put in the kiln. Again, in the dry-clay process, there is no kneading whatever, for the clay is ground up in an almost dry state (there being but very little water at any time put in the grinding pan) and is pressed into the form of bricks rather than moulded.

126. Brick Burning. In a previous article it was pointed out that, to make a good brick, proper burning was just as important as a suitable clay composition, and such is indeed the case, for, whilst good clay may be spoilt by bad burning, it often enough happens that poor and troublesome clay is turned into good bricks by the exercise of care and skill with the burning process. The cost of production is also largely

affected by the method of burning. Brick-makers seem to have recognised these points, and have almost departed from the old-fashioned "clamps" and open kilns, and closed kilns on the continuous principle are almost universally adopted.

127. A Clamp is formed by making a foundation of burnt bricks, and then stacking the raw bricks in courses with a layer of coke between each course, the outside or casing being generally formed with burnt bricks. During the stacking of the raw bricks, flues, filled with coke, are formed about five or six feet apart, all over the clamp. These flues are connected with "live holes" about 9 in. x 9 in. in cross section, which run right across the clamp. The stack, or clamp, therefore contains distributed throughout it enough of the fuel to burn the bricks; and when everything is ready fires are started in the "live holes" and continue until the whole of the fuel is consumed, by which time the bricks are supposed to be burnt. Burning by this method is very unsatisfactory, for the bricks are not uniformly affected by the fire, and consequently a difference occurs in the quality of the bricks from the various parts of the clamp.

In cases of temporary demand in outlying districts it often happens that clamp-burning is the only method possible of adoption. It is, therefore, just as well to be acquainted with particulars as to how to proceed.

128. Open Kiln. An open kiln is a roofless building, rectangular in plan, with large openings at each end, and "fire holes" about 3 ft. 6 in. apart along the sides, the walls being of substantial thickness, and built with burnt bricks. The process of burning in one of these open kilns is as follows:—

The kiln is completely filled with the raw bricks, which are so stacked as to leave access by the fire to as much as possible of each. After the kiln is filled, the openings in the ends are filled up with burnt bricks and sealed with clay. Fires are then lighted in the fire holes along the sides, but the temperature is gradually raised during the first two days so that the moisture in the bricks may be slowly expelled. As soon as the bricks are relieved of the contained moisture, the temporary roof of iron, etc., put on while stacking the bricks, is removed, the fires are set fully going, and the temperature is raised to a very high degree. It takes about six days from the time of "lighting up" to fully burn the bricks to a condition of hardness, after which the firing ceases, and the fire holes are partially stopped up to prevent the cold air entering too freely. Two additional days are allowed for cooling, and the bricks are then ready for removal from the kiln.

As in the case of clamp-burning, though of course not to

such great extent, difference in quality occurs, for the bricks are by no means equally burnt throughout the kiln. A great waste of heat also takes place in these kilns owing to the fact that the draught has an outlet over the whole top of the kiln; and for the same reason the fuel is not fully consumed, as can be easily understood by anybody who has seen the dense, black smoke issuing from these kilns. Open kilns are built to contain from 80,000 to 100,000 bricks.

129. Closed-down Draught Kilns, which are a great improvement on those of the open kinds described in the last article, have a permanent roof of brick, arched after the fashion of a barrel vault. The ends are also built up, permanently, to a greater extent than in the case of the open kilns, the openings therein approximating more nearly to what may be called doors. Fire holes are made along the sides in the same manner as in the case of the open kiln, but the draught is arranged in a better and altogether different plan, as the following will serve to show:—

Inside baffle walls built about a foot from and parallel to the side walls, and reaching nearly to the roof, cause the draught to have an upward direction until near the top of the kiln, after which the direction is downwards through the bricks to be burnt, and under the floor by a flue which is connected with a smoke stack. In these kilns the heat is more equally distributed over the contents than in those on the open plan, and consequently the colour is fairly uniform and the degree of hardness more nearly constant. Again this arrangement of draught provides for the retention in the kiln of the heat for a much longer time, so that more work is got out of the fuel.

There are many kinds of patent kilns, the special features of which are improvements in one way or another on the simple principle of the down draught kiln, and some are so well designed as to burn very good facing bricks, uniform in colour. Most of the splendid double-faced bricks used in the Australian States are burnt in these kilns.

130. The Continuous Kiln is certainly a remarkable improvement on all earlier forms of kilns, and is the conspicuous feature of modern brick manufacture. In almost every brickyard of any importance there is to be found a continuous kiln with an output capacity of from 100,000 to 240,000 per week. The kiln made on the arrangement as patented by the inventor, after whom it is called, is described in the following article:—

131. The Hoffman Kiln is a massive, brick, circular-shaped building with a high smoke stack rising from the centre, and

roofed with light timbers and galvanised iron. Inside a large arched chamber like a railway tunnel is formed parallel to the outside, that is to say, it is annular in plan. This continuous tunnel is subdivided crosswise into compartments or chambers, usually 12 in number. Each of these chambers is connected with the central space leading to the smoke stack, and is fitted with arrangements for regulating or cutting off the draught by means of dampers. An arched opening to each chamber is also made in the outside of the kiln. The process of stacking the raw bricks, burning, and removing those which have been burnt goes on continuously at the same rate, and, together with the action of the draught, may be described as follows:—

Let it be supposed for the purpose of description, that a 14-chamber kiln is under notice. The external archways of two chambers are open; all the others are bricked up. Let these two chambers be called Nos. 14 and 1 respectively. Raw or green bricks are being wheeled into, and stacked in No. 14. Cool, burnt bricks are at the same time being wheeled out of No. 1. The fuel is being supplied into, and the fire is at its greatest temperature in chambers Nos. 7 and 8. The only partition is between Nos. 13 and 14; and the only flue open to the smoke stack is that from No. 13. The course taken by the current of air is therefore as follows: It enters at openings Nos. 14 and 1, and is drawn through the chambers Nos. 2, 3, 4, 5, and 6 to the fire; its action as it passes over the bricks just burnt is to cool them, and it becomes quite hot before it gets to the fire. The hot gases and fumes as they leave the fire are drawn towards the only outlet, viz., by way of the open flue in No. 13. These hot gases have therefore to pass through the chambers Nos. 9, 10, 11, 12, and 13, which contain bricks *to be burnt*; and it consequently warms and drys them ready for the fire. Bricks, for instance, in No. 13, will just be getting the hot gases, and the moisture in them will be leaving in form of steam, and, as each chamber is nearer the fire, the bricks will be hotter and nearer the firing temperature. From the foregoing it will be seen that very little heat is lost, while the combustion is nearly perfect, for the fuel is supplied in the form of small coal through holes in the roof of the tunnel, and it is no sooner dropped among the red hot bricks than it is in a state of fierce combustion. By the time that No. 1 chamber is emptied the filling of No. 14 is completed; the partition is made at the end of No. 14 instead of at No. 13, and the fire travels on one chamber ahead—and so on goes the process. The partitions were originally iron shutters, which were lowered and raised from the top as required, but in some of the later kilns the partitions are simply made with brown paper

or some such light material pasted over the bricks to stop the draught. The light partition is easily destroyed by the draught and heat, when the flue in the chamber ahead is opened.

132. There are, however, many other kinds of continuous kilns in operation, but all are more or less based on the principle of the Hoffman. A kiln much in use about Sydney is rectangular instead of circular in plan, with rounded ends, and the continuous chamber consists of two straight tunnels built side by side with the flue leading to the smoke stack in between them. Small openings or archways at each end connect the tunnels and provide for continuity of draught. Another difference, which is also an improvement, is that there is a flue to the smoke stack from each side of each chamber instead of as in the Hoffman—only one from the inside.

133. The Continuous Kiln as it is at present is only useful for burning common bricks, for, as pointed out before, the colour is very uninviting, and the shape is not altogether as good as is to be desired, whilst a source of some trouble in the patent kiln is the "steaming," as, despite all care, the bricks are sometimes rendered into "slush." The great feature of the continuous kiln is, however, to be found in the cost of operation. Common bricks are produced from these kilns comparatively cheaply, as compared with bricks manufactured in other kilns.

134. Classification and Quality of Bricks. Bricks are classified in accordance with the methods of manufacture as follows:—

(1) *Sandstocks* or hand-made.
(2) *Plastics* machine-made or wire-cut.
(3) *Dry pressed* machine-made.

These classes are again subdivided as regards quality:—

(a) *Callows* or under-burnt bricks.
(b) *Clinkers* or mis-shapen and over-burnt bricks.
(c) *Ordinary* good common bricks.
(d) *Picked* or the best among the common ones.
(e) *O.K.* or open kiln bricks.
(f) *Double-pressed* or those which are specially made (generally by the plastic process), twice pressed and specially burnt.
(g) *Enamelled bricks.*
(h) *Texture bricks.*

135. Callows are generally bought at a low price and used for interior walls in construction of a poor character. It is, however, needless to say that such bricks should on no account be used in building work, for they have a tendency to crumble to pieces, and they also hold moisture and make damp walls.

136. Clinkers are, like callows, to be purchased at a low price, but their most serious defect is their bad shape. They are usually used for foundations and for rough paving. This kind of brick is got from around the fire holes in the kiln, and their ill shape is due to the overpowering intensity of the heat at these places.

137. Ordinary Common Bricks are those, either hand-made, wire-cut, or dry-pressed, which are of the average quality turned out nowadays. As these bricks are used for the body of the building in most cases, every care should be taken to see that they are of good quality. A clear, ringing sound should be given out when two are clapped together. A broken section should show a partial vitrification of the mass; and a sharp instrument, such as a pocket knife, should make no impression. Tests should be made when selecting bricks, to ascertain the power of resistance to compression or transverse stresses, and also to determine the percentage of water absorption. A common brick to be of good quality should stand at least a pressure of 1,120 lbs. per square inch; and should not absorb more than 6 per cent. after being 24 hours immersed in water. In addition to these qualities, the brick should be regular in shape and have sharp edges. Common bricks are burnt mostly in the continuous kilns, but, in the case of sand-stocks, the burning is done in open kilns.

138. Picked Bricks are the best of the common ones, and should possess, beyond question, the qualities described above. As a matter of fact, to get good, ordinary bricks it is necessary to specify them to be "picked," otherwise a fair proportion of the more presentable clinkers and callows will be put in.

139. O.K., or Open Kiln Bricks. A very good kind of common brick is made by the dry process and burnt in the old-fashioned kilns. These O.K. bricks, as they are called, are much used for facing purposes, where a double-pressed brick would be too expensive. Greater care is taken in handling these bricks when removing from kiln to the building.

140. Double-pressed Bricks are made with the greatest care, and are used for such purposes as facing bricks for the best class of buildings and for sanitary work. As their name implies, they are again pressed after being taken out of the moulding or wire-cutting machine. They are burnt with special care in the down draught and cupola kilns, as colour in this class is often a matter of the greatest importance. A good, double-pressed brick should possess in a greater degree all the qualities enumerated in Article 137. The resistance to compression should at least be 2,000 lbs. per square inch, and the

water absorption not more than 3 per cent. The opposite faces should be perfectly parallel, the edges should be sharp and unbroken, and there should be no cracks showing. Double-pressed bricks, such as described, are easily enough obtained in the Australian cities, and should be used for important work, for they are practically imperishable. These bricks are either white or of a very dark colour. A much less durable kind of double-pressed brick of light red and buff tints is much used on account of the soft tone of colour effect obtained; but they are by no means so durable.

141. Enamelled Bricks are very expensive, and consequently are sparingly used. They are used for such purposes as linings of lavatories and light areas. The body of this kind of brick should be as good as the best double-pressed, and the enamel should be free from cracks.

141a. Texture bricks. There are many texture bricks available, which are marketed under various trade names. They are manufactured by the plastic process and have very lasting qualities. They are available in many colours, and are often used in place of O.K. face bricks, but are more expensive.

142. The Following Table is interesting as indicating the water-resisting properties of the local bricks. The selection from among a great number has been made in a careful manner, with a view of obtaining a fair average of the building bricks. The samples were dried and then soaked in water for 24 hours.

TABLE XIV

Showing Absorption of Water by different Varieties of Bricks made in Sydney District.

No.	Locality	wt. rec'd		wt. dried		wt. wet		Per cent. Porosity	Dimensions in inches
		lb.	oz.	lb.	oz.	lb.	oz.		
1	Petersham, Double-pressed.........	8	7¼	8	7¼	8	12	3·51	
2	Petersham, Double-pressed.........	8	1¼	8	1	8	6¾	4·51	9 x 4 x 3
3	St. Peters, Common.	8	0	8	0	8	7¾	6·06	,, ,, ,,
4	St. Peters, Common.	9	1¼	9	0¾	9	8	5·01	9¼ x 4¼ x 3
5	Surry Hills, Common	8	1	8	1	8	12½	8·92	8¾ x 4¼ x 3
6	Hurstville, Common.	8	4¼	8	4½	8	12	5·68	9 x 4½ x 3
7	,, ,,	4	8¼	4	8	4	14	8·33	,, ,, ,,
	,, ,,	4	9½	4	9¼	4	15½	8·53	,, ,, ,,
	,, ,,	4	13	4	12	5	2¾	8·88	,, ,, ,,
8	Merrylands, Common	4	2¼	4	1¾	4	7¼	8·35	,, ,, ,,
9	,, ,,	8	13	8	13	9	13⅓	11·70	,, ,, ,,
10	,, ,,	9	2	9	1	9	14¼	9·14	,, ,, ,,
11	Surry Hills, Common	7	10½	7	10¼	8	6¼	9·8	8¾ x 4¼ x 3 3/16
12	,, ,,	8	3½	8	2¾	8	10¼	5·7	,, ,, ,,
13	,, ,,	7	12¼	7	12¼	8	7½	9·05	,, ,, ,,

Specimens Nos. 7 and 8 were broken into halves prior to being tested.

143. Strength of Brickwork. Until quite lately there has been very little information of an accurate character relating to the strength of brickwork. Several well-known authorities

TABLE XV*

Showing Crushing Strength of Bricks Tested as Received without Preparation.

No.	Description	Crushing Force per sq. in. in lbs.	Crushing Force in lbs.	Total Force to Crack in lbs.	Area Exposed in sq. inches	Size in inches	Remarks
1	White	2,026	28,500	23,000	14 1-16	4½ x 3⅛	Tested with ends bedded in sheet lead
2	Blue	2,747	34,000	—	12⅜	4⅛ x 3	
3	Red	746	10,500	—	14 1-16	4½ x 3⅛	
4	Yellow	2,086	24,000	—	11½	4¾ x 3¼ x 1⅝	
5	White	4,305	38,750	31,000	9	4 x 3 x 1½	
6	Blue	2,696	30,000	—	11⅛	4¼ x 2¾ x 2½	
7	Blue	2,818	31,000	10,000	11	4 x 3¼ x 2¼	
8	a 1	1,537	20,750	17,500	13½	4½ x 3	Common Bricks
9	a 2	1,592	21,500	16,250	13½	4½ x 3	
10	a 3	1,037	14,000	—	13½	4½ x 3	
11	b 1	1,131	14,000	—	12⅜	4½ x 2¾	
12	b 2	1,939	24,000	19,000	12⅜	4½ x 2¾	
13	b 3	1,373	17,000	13,250	12⅜	4½ x 2¾	
14	c 2	1,238	16,250	15,000	13⅛	4⅜ x 3	
15	d 3	1,371	18,000	15,250	13⅛	4⅜ x 3	
16	e 1	1,352	17,750	—	13⅛	4⅜ x 3	

* From tests made by Professor Warren.
Specimens Nos. 4, 5, 6, and 7 were radiating bricks for sewer.

TABLE XVI

Showing Transverse Tests made on Bricks at Sydney Technical College.

No.	Sizes of Bricks in inches			Span in inches	Weight of Bricks in lbs.	Breaking Load in lbs.
	Length	Breadth	Depth			
1	9·2	4·25	3	7	9·5	2,408
2	9·12	4·37	3·1	7	9·25	1,792
3	9·12	4·31	3	7	9·25	1,680
4	9·12	4·37	3	7	9·3	2,016
5	9·18	4·31	3·06	7	9·5	2,240
6	9·6	4·37	3·03	7	9·25	2,552
7	9	4·5	2·9	7	7·8	1,735
8	9	4·5	3·02	7	7·8	2,192
9	9·25	4·62	2·98	7	7·3	4,370
10	9·12	4·37	3·06	7	7·3	5,240
11	9·25	4·37	2·96	7	7·3	4,345
12	9·12	4·5	2·94	7	7·2	2,285
13	9·25	4·3	2·99	7	7·5	3,633
14	9·12	4·5	3·03	7	7·5	5,290

Specimens 1 to 6 inclusive were Common Bricks Dry-pressed from St. Peters.
Specimens 7 to 13 inclusive were Plastic Wire-cut from Liverpool, and were of a dark red colour.

on the strength of materials have given the load for brickwork, but the qualities of bricks and mortars vary so much in different places, that these loads have been from a practical point of view of very little value. For instance, in "Civil Engineering," by Professor Rankine, the strength of brickwork in piers is given as about from 800 to 1,000 lbs. per square inch, but this is of very little use to the engineer or architect who has to use bricks and mortars of ever-varying quality.

A great amount of information has been gained from the many tests made in different parts of the world on different kinds of bricks and mortars; but it was not until 1887 that

TABLE XVII

Showing Results of Tests made to ascertain Strength under Compression of Brick Piers.

	Kind of Bricks Used	Size of Pier	Mortar and Proportion of Ingredients	Age of Pier in months	Average Crushing Load in tons per sq. ft.	Average Strength of Individual Brick in tons per sq. ft.	Safe Load 1/5 of Crushing Load in tons per sq. ft.
1	Staffordshire Blue, First Series	6ft. x 18in. x 18in.	Lime Sand 1 to 2	3·5	74·3		14
2	,, ,, ,, ,,	,, ,, ,,	,, ,, ,,	10	73·7		14
3	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	3·5	72·8		14
4	,, ,, ,, ,,	,, ,, ,,	,, ,, ,,	10	82·5	780	16
5	,, ,, Second Series	,, ,, ,,	,, ,, ,,	3·5	103·1		20
6	,, ,, Third Series	6ft. x 27in. x 18in.	Lime Sand 1 to 2	5	114·3		22
7	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	5	135·4		26
8	Leicester Red, First Series	6ft. x 18in. x 18in.	Lime Sand 1 to 2	3·5	30·7		6
9	,, ,, ,, ,,	,, ,, ,,	,, ,, ,,	10	34·1		6
10	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	3·5	58·5		11
11	,, ,, ,, ,,	,, ,, ,,	,, ,, 1 to 4	10	50·4	362	10
12	,, ,, Second Series	,, ,, ,,	,, ,, ,,	3·5	86·4		17
13	,, ,, Third Series	6ft. x 27in. x 18in.	Lime Sand 1 to 2	5	45·4		9
14	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	5	83·0		16
15	Gault, First Series	6ft. x 18in. x 18in.	Lime Sand 1 to 2	3·5	21·9		4
16	,, ,, ,,	,, ,, ,,	,, ,, 1 to 2	10	21·6		4
17	,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	3·5	17·8		3
18	,, ,, ,,	,, ,, ,,	,, ,, 1 to 4	10	30·0	189	6
19	,, Second Series	,, ,, ,,	,, ,, ,,	3·5	49·6		9
20	,, Third Series	6ft. x 27in. x 18in.	Lime Sand 1 to 2	5	31·1		6
21	,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	5	51·3		10
22	London Stocks, First Series	6ft. x 18in. x 18in.	Lime Sand 1 to 2	3·5	10·4		2
23	,, ,, ,, ,,	,, ,, ,,	,, ,, 1 to 2	10	12·5		2
24	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	3·5	14·9		3
25	,, ,, ,, ,,	,, ,, ,,	,, ,, 1 to 4	10	19·7	84	4
26	,, ,, Second Series	,, ,, ,,	Lime Sand 1 to 2	3·5	18·3		3
27	,, ,, Third Series	6ft. x 27in. x 18in.	,, ,, ,,	5	18·6		3
28	,, ,, ,, ,,	,, ,, ,,	Cement Sand 1 to 4	5	39·3		8
29	Sydney, Common	4ft. 8in. high	Cement Sand 1 to 2	4	176		35
30	,, ,,	9in. x 9in. in Cross	,, ,, 1 to 4	4	152	295	30
31	,, ,,	Section	Lime Sand 1 to 2	4	121·5		24
32	,, ,,		,, ,, 1 to 4	4	80		16
33	American, Common	From 2ft. to 10ft. high	Cement Sand 1 to 2	24	124·5	1170	24
34	,, Face	About 12in. x 12in. in Cross Section	,, ,, ,,	18 to 23	174	890	34

Tests 1 to 28 inclusive made by Science Committee, R.I.B. Architects, during 1895, at West India Docks, London.
Tests 29 to 32 inclusive made by Professor Warren, during 1899, at Sydney University.
Tests 33 and 34 made by Committee of American Society of Civil Engineers, during 1887–8, at Watertown Arsenal.

tests were made (at least none have been recorded) to determine, if only approximately, the difference which exists between strength of bricks and mortar, and strength of brickwork built up with same.

During that year a number of important and interesting tests of the strength of brick piers compared with individual bricks were made by a Committee of the American Society of Civil Engineers, at Watertown, in the United States of America.

An abstract of the result (averaged where possible) of the tests is given by numbers 33 and 34 in the Table No. XVII. The abstract comprises cases of piers as nearly as possible similar in shape and size so as to facilitate comparison.

These tests showed a great difference between the strength of bricks and the strength of brickwork built up with them. No. 33, for instance, shows brickwork which failed at 124·5 tons per square foot, that was built up with bricks the crushing strength of which, tested individually, was 1,170 tons per square foot. They also showed, what was only of course to be expected, that the mortar had a great deal to do with the strength of brickwork less in strength than that built up with face bricks, lime, and cement mortar respectively. A feature of importance to be noticed in the results of the American tests is that the common bricks, though much the strongest individually, made brickwork less in strength than that built up with face bricks, proving that to have good, strong brickwork the shape of the bricks must be good.

As to the actual strength of brickwork the tests did not afford much information, for the piers were of small cross sectional area, and the ordinary conditions of bond, a matter considerably affecting the result, were not existing.

The matter does not seem to have had any further attention until during 1895, when a number of tests were made in connection with the Royal Institute of British Architects, by a committee composed of prominent members thereof, aided by the advice and assistance of Professor Unwin.

A most elaborate and interesting account of the methods of testing (together with the results minutely recorded) is published in the Journal of the Royal Institute of British Architects, and from this account the result Nos. 1 to 28, Table XVII, have been taken. The value of the tests was, to some extent, impaired, because, unfortunately, some of the piers were built by inserting closers of a soft kind, and the strength of these particular ones was affected to some extent.

The tests 29 to 32 were made by Professor Warren, at the Sydney University, during 1899, and of all in the table they are the most interesting to Australian builders. The tests

were carried out in a most careful manner on common dry-pressed bricks of the average quality used in Sydney. The results may be relied on, and should be very useful when designing piers and other brickwork where compression stresses are to be resisted. The 9 in. x 9 in. piers were, however, of course, without closers, consequently they stood stresses higher than what could be expected from piers in which closers were necessarily used. In the table, the safe loads as $\frac{1}{5}$th of the crushing loads in the tests are consequently too high. Professor Warren, in the paper describing the tests, recommends 15 to 20 tons per square foot as the safe load for good brickwork in 2 : 1 cement mortar, and 9 tons per square foot as safe load for good brickwork in 2 : 1 lime mortar.

It will be seen by the table that all tests show a wide difference between the crushing strength of bricks individually and brickwork.

The photographs and drawings which were taken at all the tests have, however, clearly shown that the failure is not due to crushing force altogether, but to lateral tension and shearing, so that it will at once be evident that when these are the causes of failure the mere crushing strength of a brick cannot represent the strength of a brick pier or wall built with similar bricks.

According to S.A.A. C.A.1 the allowable pressure on brickwork built in cement mortar is 15 tons per square foot, and on brickwork built in lime mortar 8 tons per square foot, provided the slenderness ratio $\dfrac{\text{Height}}{\text{Least dimension}}$ does not exceed 6. For higher slenderness ratios, the stresses should be reduced as:—

$\dfrac{L}{D}$	% reduction in stress from that given above
8	20
10	40
12	60

An isolated pier should not have a slenderness ratio of more than 12.

144. Terms used in Connection with Brickwork:—

Header: A brick laid with its length across the wall.
Stretcher: A brick laid with its length along the wall.
Bat: Portion, such as half, or three-quarters of a brick.
Closer: A quarter brick used as at A, Fig. 33, to make up in course of headers. *A Queen Closer* is a portion about 9 in. x $2\frac{1}{4}$ in. x 3 in. obtained by halving a

brick longitudinally. *A King Closer* is a brick with a corner cut off so as to reduce its head to show as a quarter brick on the surface of the wall.

Frog: Is the indent on one of the larger faces of the brick. It is made so as to form a key for the mortar, and the brick should always be laid with the face containing it uppermost.

Course: Is a layer of bricks, such as, for instance, the upper layer in Fig. 33.

Bond: Is the term given to the method of interlacing or overlapping when laying the bricks so as to cause them to hold to each other, and to spread the weight of each over as many of the others as possible.

The overlapping or bond is provided for by arranging the bricks so that in any one course there shall be none (or as few as possible) of the vertical joints directly over those joints in the course underneath. The distribution of the bricks throughout the wall to bring about this result is a matter of a complicated nature, and depends not only on the skill of the layer but also on the shape of the bricks.

144a. Size of Brick. The average size of a brick is 9 in. x $4\frac{3}{8}$ in. x 3 in. The width is the most important dimension, and must be such to allow of two headers being placed across the stretcher and still leave $\frac{1}{4}$ in. for a vertical joint. This is necessary, as will be seen in the following Articles, to give correct bond. Plastic bricks 9 in. x $4\frac{3}{8}$ in. x 2 in., and briquettes $6\frac{1}{2}$ in. x 3 in. x $1\frac{1}{4}$ in., are available in many colours, and are mainly used as a facing to open fireplaces and ornamental gables.

145. There are Several Systems or Kinds of Bond, but all are based on the same general principle. Those most commonly used are denoted as follows:—

(1) English Bond.
(2) Flemish ,,
(3) Colonial ,,

English Bond is considered to be the best, as the breaking of joints is complete. On the surface of the wall this bond shows courses of stretchers and headers, alternately, for all thicknesses of walls from 9 in. upwards.

Figures 33 to 37 are isometric views of English bond in walls of various thicknesses with corner junctions at right angles. The top course is, in each case, shown as raised up, so as to illustrate the difference between the arrangement of bricks in it, and the course next underneath. It will be seen by the sketches that an external distinguishing feature of this bond, is, that a course of headers occurs between each two

courses of stretchers, or, in other words, that courses of headers occur alternately.

It will therefore be clear that in any particular thickness of wall the arrangement of the bricks in all heading courses will be alike, and so also will all stretching courses be the same.

The use of closers as provided for the breaking of joints in the heading courses is shown by these sketches.

Figures 33, 34, 35, 36, and 37 represent, respectively, walls 9 in., 13½ in., 18 in., 22½ in., and 27 in. in thickness.

146. Flemish Bond. In this bond the bricks are so arranged that on the faces of the walls, stretches and headers occur alternately in every course. Fig. 38, which is an example of Flemish bond in a 9 in. wall, shows, on the face, alternate stretches and headers in each course, and also that every header is directly over the centre of a stretcher. This bond is not nearly so strong as English bond, for, as shown by Figs. 38 to 42, which illustrate the arrangements for various thicknesses of walls, it is necessary to use a large number of bats, and, in addition to this defect, there are also, at certain places, straight joints from bottom to top of the wall. These defects notwithstanding, this kind of bond is much used in the work of a superior character on account of an idea that it looks better than English. Flemish bond is subdivided into two kinds, viz.:—(1) *Double*; (2) *Single*. The Figs. 38 to 42 represent, respectively, the arrangements for double Flemish bond in walls 9 in., 13½ in., 18 in., 22½ in., and 27 in. thick. It will be noticed by the drawings that in this kind both sides of the walls are alike—in other words, that every course shows the same arrangement of headers and stretchers on the front as on the back. On this account the bond is called "double." This kind is, however, the weakest, as straight joints occur at intervals on each side of the wall. To overcome this serious defect, and at the same time to preserve the appearance of Flemish bond in the external face, the bricks are so arranged as to be Flemish on the face and in English bond in the remainder of the thickness of the wall. Fig. 43 is an example of a 3 brick or 27 in. wall in "single" Flemish bond on face and English bond in the remainder. It will be seen by this illustration that in alternate courses on the face the headers are only bats—"snap headers" is the technical term for them. On this account "single" Flemish bond does not appear at first sight to be as good as "double," but it is really much better, for the straight joints occur at one side only. Limited space does not allow of more than one example of single Flemish bond being given, but the student can, himself, easily draw the other thicknesses of walls by following on the principle as illustrated in the

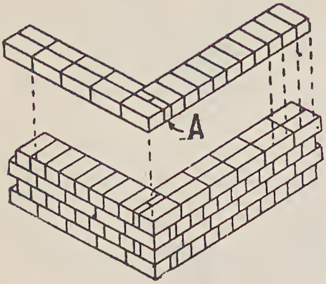


FIG. 33

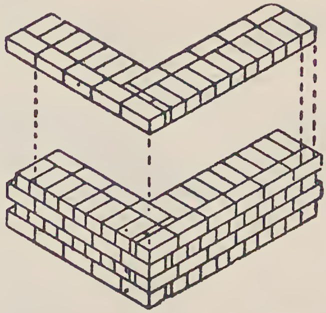


FIG. 34

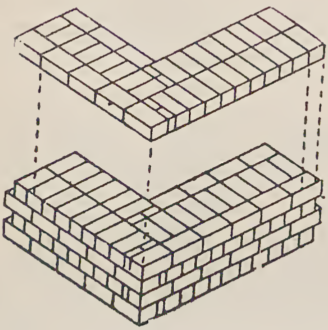


FIG. 35

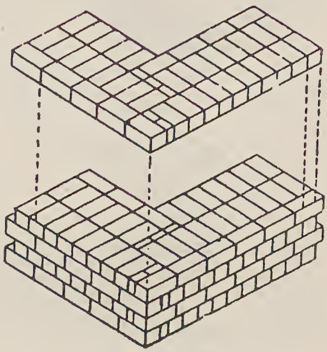


FIG. 36

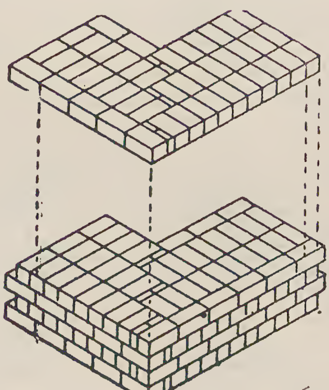


FIG. 37

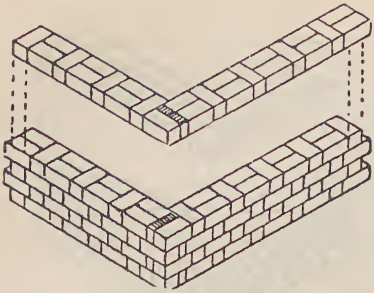


FIG. 38

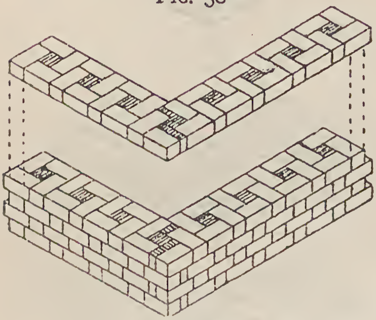


FIG. 39

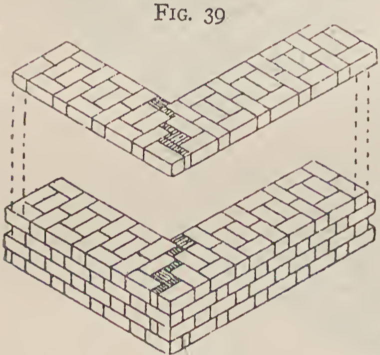


FIG. 40

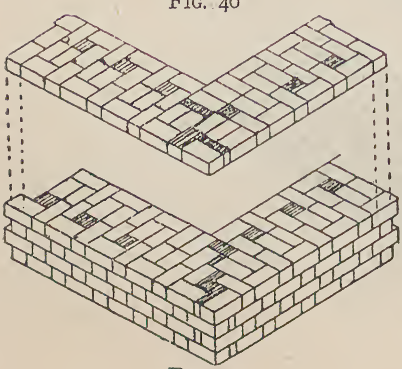


FIG. 41

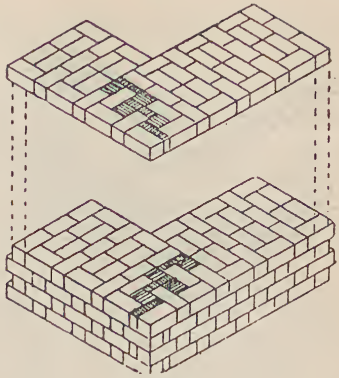


FIG. 42

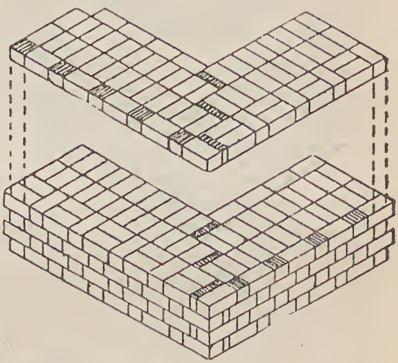


FIG. 43

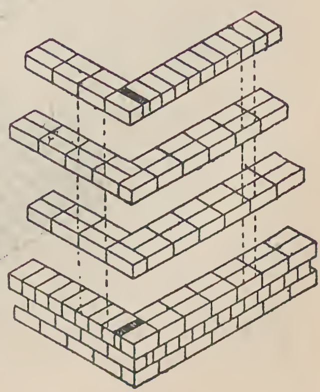


FIG. 44

given example, viz.:—English bond in the body of the wall with just the facing of Flemish, using snap headers in alternate courses.

147. Colonial Bond is the Australian name for the arrangement which consists of three courses of stretchers to every one course of headers. Fig. 44 illustrates this bond. It is of course only applicable to walls 9 in. thick, but in such walls it is as good as any other kind, if properly built, for in the stretching courses there is *half* bond which must give the wall a great deal of strength longitudinally. Bricklayers are, however, in the habit of running up the three courses of stretchers on the face first, and then "backing" up with the three courses of inner stretchers. This is done in the interest of speed, but it greatly interferes with the quality of the work, for under such conditions of laying it is impossible to properly flush up the middle joint. Colonial bond is much used in cottages, and small houses, in which walls 9 in. thick are about the usual thickness adopted.

148. Raking Bond. It will be seen by the sketches (Figs. 33 to 37) that in English bond, headers occur in greater number than stretchers. In a 13½ in. wall, for instance, there are only half as many stretchers as headers, and the proportion is greater as the thickness of the wall is increased. Walls of great thickness in English bond are therefore, to a certain extent, weak longitudinally. This want of longitudinal tie is remedied by what is called *raking bond*, that is by putting the bricks diagonally instead of in heading direction between the outside lines of stretchers in the stretching courses. Raking bond is, of course, not possible, nor is it needed in walls less than 22½ in. thick. This bond is sometimes called diagonal bond.

149. Piers in most cases carry more weight per square foot of cross sectional area than walls, and consequently every care should be taken, when building them, to have the best bond. Some examples of bonds for piers are given by Fig. 45. It will be seen from the sketches that all piers above 14 in. x 14in. are built with closers. The closers are necessary to provide for the breakage of joints to get the bond, but unless of a quality equal to the other bricks, and of proper size, they are a source of weakness. This was clearly illustrated by the tests made by the Committee of the Royal Institute of British Architects which have been referred to in Article 143, *ante*.

150. Reveals. Examples of the arrangement of the bricks at the finish of walls round doors and window openings are given by Figs. 46 and 47. The thickness of the wall (B Fig. 46) in

front of the door or window frame is called the *Reveal*, and the balance of the thickness of the wall (A Fig. 46) is called the jamb or recess. Sometimes the inner corner of the jamb is cut off, or, as it is termed, splayed. Of course, there is no limit to the variety of reveal and jamb, there being so many kinds of door and window frames, and different thicknesses of walls. Fig. 46, for instance, shows 4½ in. reveals in walls 13½ in., and 18 in. thick in English bond; and Fig. 47 shows similar reveals for the same size walls in Flemish bond; but in each case the reveals might have been 9 in. or the jambs splayed, and so on, the possibility of variation becoming greater as the thickness of the walls is increased. The examples given will, however, serve to indicate in a general way the method of finishing round doors and windows.

151. Brick Footings. The matters relating to the design of bearing area and strength of footings have been dealt with in Articles 19, 20, and 21, *ante*, so that at this stage it is not necessary to deal with more than the question of bond. Figures 8 (Article 33 *ante*) and 48, show two cases of offset courses as footings. In Figure 8 each offset is part of a layer composed of two courses of bricks, so arranged and disposed as to be in the same bond as if in a wall of similar thickness. A *footing* built in such a way is, therefore, composed of a number of horizontal slices of walls (in English bond), the top slice being 4½ in. wider than the wall, and every other slice being 4½ in. wider than the one next above. Such a footing will be strong, and will be in accordance with rule laid down in Article 23 *ante*. In Figure 48 the offsets are parts of single layers of bricks. Those layers, or courses, which are multiples of 9 in. wide, are composed altogether of headers, while those which are not, have one row of stretchers, but it will be noticed that the stretchers are in all cases placed in or near the middle of the footing.

152. Hollow Walls. It is now becoming a general practice to build external walls, which are exposed to the weather, in two parts with a space between, instead of solid throughout. This is done with a view to preventing the moisture, which is absorbed by the face of the wall, from passing right through. Fig. 48 gives a view of a *hollow* or *cavity* wall. It will be seen that the front part is 4½ in. thick, and that there is a space of 2¼ in. (this space may be any width between 2 in. and 3 in.) wide between it and the remaining or inner part. This space prevents the passage of any moisture to the inside of the wall, and also acts as a non-conductor, thereby preventing the too ready passage of heat, so that the interior of the house is kept cool in hot, and warm in cold, weather. In the case illus-

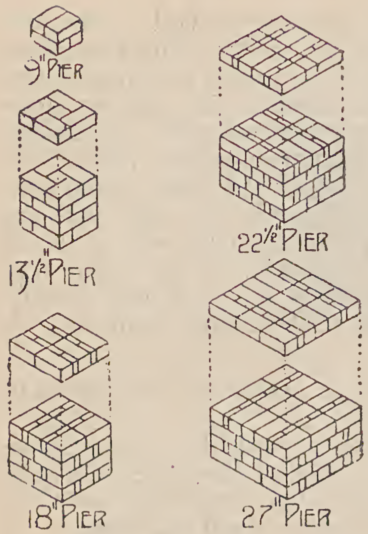


FIG. 45

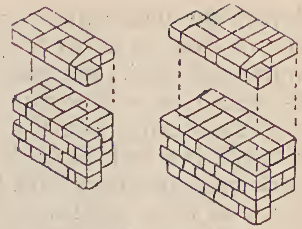
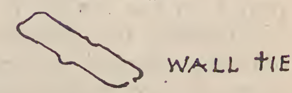


FIG. 47



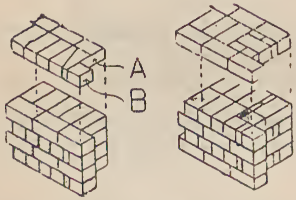


FIG. 46

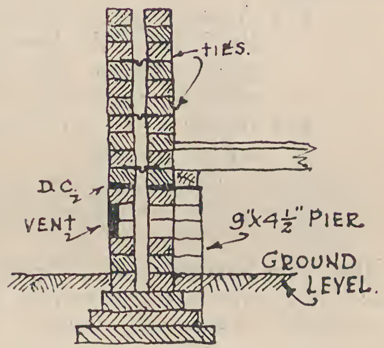


FIG. 48

trated by Fig. 49, the thickest part of the wall is shown on the inside, and such is the best, for the thinner part only, under such circumstances, is subject to the action of the weather, whilst the thick part is that which carries the weight of floors and roof and should be on the inside. The front part may, therefore, be considered as a protecting face wall, which, as far as strength is concerned, has nothing more to do than support itself, and it even has not that much to do, altogether, for the two parts are connected together by metal ties spaced at frequent intervals as indicated in Fig. 48. A very good, and, at the same time, cheap kind of tie is made from ¼ in. galvanised iron wire bent as shown in Fig. 49 and Fig. 48. Iron ties should be galvanised to prevent oxidation, and they should be built in at intervals of 2 feet or 2 feet 6 inches long every third course or fourth course. The mortar droppings are prevented from getting into the cavity as follows: A piece of

timber the width and length of the cavity is laid on the first row of ties, so as to be just over the cavity. The next three courses of bricks are then laid, and the batten is removed, and the new row of ties put in. The batten is then put on again over the cavity, and the next three courses built up—and so on until the wall is built. The most troublesome part of the work in connection with hollow walls is the finish round window and door openings, for if this part be not well done the rain will get through, and an ugly dampness will show all round on the inside of the openings. Fig. 50 shows one way of finishing the reveals. The heads of the door and window openings should be protected by lead flashing built in over them as shown at B Fig. 49.

153. Damp Courses are built in walls in the following positions:—

(1) As near the foundations as possible, but not above the level of the lowest part of the lowest floor for timber floors, and just above the floor level for solid floors, such as concrete built on filling.
(2) Along under the coping, when the wall is finished with a parapet.
(3) Vertically in the centre, or on the outside, when in the case of a basement wall.
(4) In chimneys just above the roof level.

154. The Essentials of a Damp Course are that it will resist the passage of moisture, and be of sufficient strength to stand the weight of the wall resting on it.

155. A Damp Course may be composed of any of the following materials:—

(a) Sheet lead.
(b) Slate set in cement mortar.
(c) Pottery.
(d) Asphalt.
(e) Patent pliable damp course material.

156. Sheet Lead is not generally used because it is expensive, but it is quite effective, and is durable, the author having had opportunity of examining courses of this material which were in good condition after being many years in use.

NOTE: Lightweight lead is not expensive, but if used should be protected with some form of bitumen, as in "Leadite" or "Leadcore." Different weights of lead can be bought in various widths to suit different wall thicknesses.

157. Roofing Slates are often used in ordinary work. The course is composed either of one or two courses of the slates carefully bedded in mortar, composed of two parts of sand and

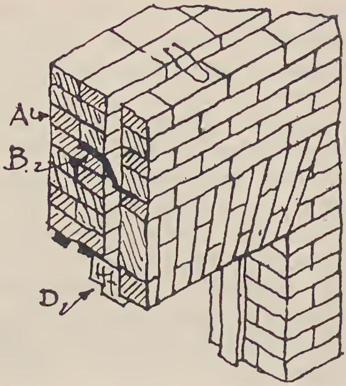


FIG. 49

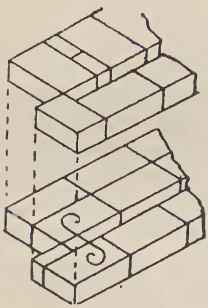


FIG. 50

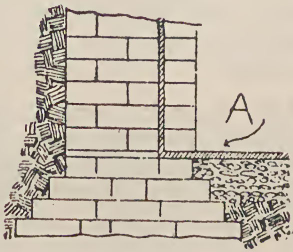


FIG. 52

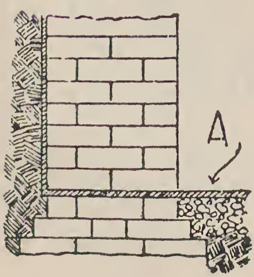


FIG. 51

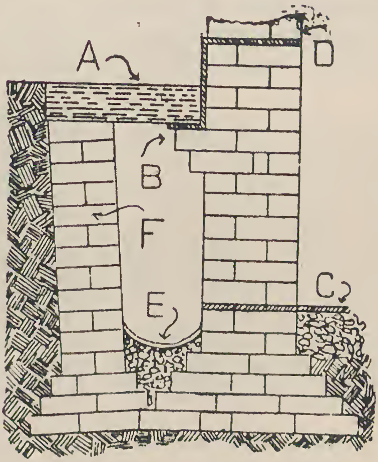


FIG. 53

one part of Portland cement. In the case of a single course the slates are lapped over each other for about 1½ in. or 2 in.; when a double course is used the lap is half a slate, or, in other words, the slates are laid in stretching bond like the 4½ in. brick wall in Figure 48. There are two important points to be attended to when laying a slate damp course. (1) Great care is to be taken that the slates are supported everywhere by the bed of mortar, otherwise they will collapse when the superimposed wall is built. The double course of slates allows of the best bedding and is therefore the best. (2) Care must be exercised so as to prevent any of the slates being broken, for the damp will rise through the slightest crack. A slate damp course properly laid is sufficiently strong to stand the weight per square foot of all ordinary walling.

158. Pottery Damp Courses are composed of thin slabs or bricks perforated with holes horizontally and burnt to a fully vitrified state. This kind of course is seldom used, for it is too thick.

159. Asphalt Damp Course is laid while in a heated state in the form of a continuous layer about ½ in. thick. It makes an excellent damp course, being quite proof against moisture, and its continuity makes it much better than those kinds of courses which are composed of materials joined together. It is, however, necessary to make sure that the right kind is obtained, for there are several kinds which are not strong enough to prevent the weight of the wall from pressing them out. The proper kind is composed of bitumen and limestone grit and becomes very hard. The following table shows the constitution of several kinds of asphalt:—

TABLE XVIII

Analysis of Asphalts (by Mr. W. M. Hamlet)

Kinds	PERCENTAGE							Specific Gravity	Weight of one cubic foot in lbs.
	Insoluble Grit	Soluble Grit.	Total Grit	Carbonate of Lime	Bitumen Soluble in Petroleum Spirit	Bitumen Insoluble in Petroleum Spirit	Total Organic Matter		
Trinidad	47·09	33·59	80·68	25·13	8·50	10·82	19·32	2·138	133
Val de Travers	2·00	87·56	89·56	86·74	7·00	3·40	10·40	2·333	145⅓
Seyssel	2·50	84·00	86·50	81·90	8·30	5·20	13·50	·312	144

Asphalt is particularly suitable for vertical damp courses. In such cases it is as follows:—

(a) Plastered in two coats, each about ¼ in. thick on the outside of the basement wall, if it be possible

to get at it. See Figure 51. It is, however, generally impossible to work from the outside of the wall, and one or other of the following methods must be adopted:

(b) The outer portion is built first, and then covered on the inner side with two coats of asphalt, after which the inner portion of the wall is built. This method is illustrated by Figure 52.

(c) The wall is built with a cavity (about 1¼ in. wide), which is afterwards filled with the asphalt while in a hot, liquid state.

160. In the case of Basements a layer of asphalt from ¾ in. to 1 in. thick should be laid on a bed of concrete about 6 in. thick all over to form a floor. The asphalt should be connected without any break whatever (as A Fig. 52) to the vertical damp course so as to absolutely disconnect the interior of the basement from anything that would conduct moisture. Very often the asphalt is topped with a layer of concrete or such-like material about 3 in. thick.

161. Pliable Damp Course Material, such as Leadite or Leadcore, which are thin sheets of lead covered on both sides with some form of bitumen, is convenient to use and is thoroughly effective. These damp courses are supplied in rolls of various widths to suit the different thicknesses of walls, and all that is necessary when laying them is to open them out along the wall and build them in.

162. A Damp Course should be of the full width of the wall on which it is laid, and should extend over bearings of all plates and bearers, except in cavity walls where it is in two pieces.

163. Air Drains. A vertical damp course may, in some instances, be dispensed with by having what is called an air drain, or dry area, on the outside of the wall. Figure 53 will fully explain what an air drain is. (F) is a retaining wall built a little distance from and extending along the full length of the building. Stone flags or concrete slabs (A) rest on the retaining wall, and on the corbelling (B) from the building wall. A second damp course should be built in at (D) above and should extend down under the flags. Connections should be made at intervals with a line of drain pipes to carry off the soakage water which may come through the retaining wall.

164. Terms used in Connection with Arches. Before describing the various kinds it will be necessary to note the terms used in connection with arches generally. CENTRE is the name given to the temporary timber frame on which the arch is

built. At times arches of large span are erected, and in such cases the centres are, on account of the long span and great weight to be carried, structures of a complicated nature. The famous centres used in the building of the arches of the Waterloo Bridge over the Thames at London afford an instance of the complicated character under circumstances of long span and great weight. This type of centre, together with other kinds of great centres, are illustrated in the "Encyclopædia of Civil Engineering" (Cresy). The builder in ordinary practice does not however meet with more than arches of moderate span, and the centre illustrated in Figure 54 is fairly representative of the kind generally used. The centre, Figure 54, consists of a couple of frames made out of pine about one inch thick, and cut to suit the form of the arch. The frames are connected along the curved edges by pieces of batten called "*lagging*," shown at B. In most cases the pieces of lagging are nailed on about an inch apart, but in the case of an important arch they are kept close together, so as to form a continuous curved surface on which the joints of the soffit of the arch are marked out to afford a guide when building the arch. The centre shown is for a span of about 3 ft. 9 in., and would not need any struts, but, as the span increases beyond this, struts as at E should be introduced. A centre is held in place by uprights placed against the reveal or jamb, as the case may be, of the opening. Wedges are introduced between the heads of the uprights and the bearing of the centre, as shown at D. The wedges, by their careful withdrawal, allow of the centre being successfully lowered without shock from under the arch. The lowering of the centre from under the arch is called "*striking*." SOFFIT AND INTRADOS are names given to the under-curved surface (C, Fig. 54) of the arch. The outer-curved surface (A, Fig. 54) is called the EXTRADOS. The inclined surface against which each end of the arch abuts (See B, Fig. 56) is called SKEWBACK. The line of the bottom of each skewback is called the SPRINGING LINE, and the distance between the springing lines is called the SPAN. The RISE is the perpendicular distance of the highest part (the crown) of the intrados above the level of the springing lines. The blocks or bricks forming the arch are called VOUSSOIRS, and the block at the crown is known as the KEY. The HAUNCHES are the parts of the arch from the skewback to some distance up towards the crown. SPANDRELS are those parts of the filling in above the arch which lie within the space marked F G and H, Figure 54.

165. It is only in works of an important character that the bricks are prepared tapered specially to fit the arch, and in most cases in ordinary practice the bricks are used in their ordinary rectangular shape. To obviate the wide joint that

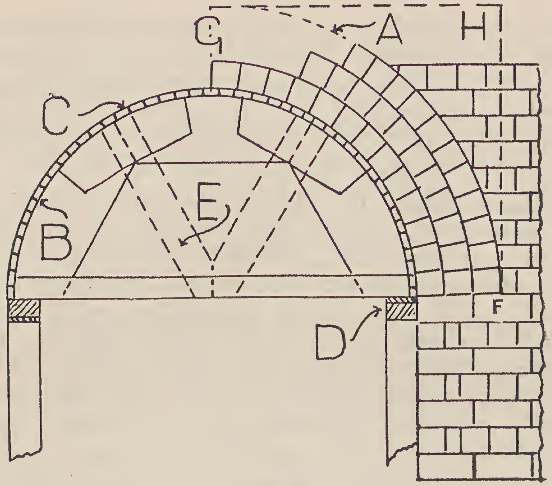


Fig. 54

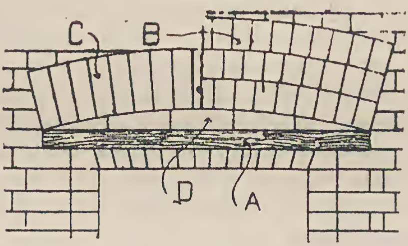


Fig. 55

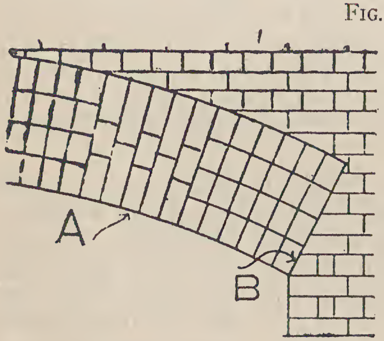


Fig. 56

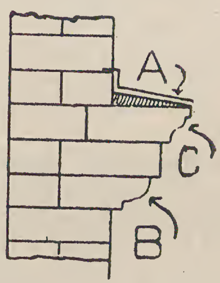


Fig. 57

would occur along the extrados if stretchers were used, it is the usual custom to build the arch in rings 4½ in. wide as shown in Fig. 54. This method is not, however, without defect, for the rings are only connected by the mortar and cannot be said to offer a combined resistance to the load on

the arch. In cases where an arch has to do important work, and where failure would be calamitous to an extraordinary degree, binding blocks are put in as at A, Fig. 56. The binding block consists of stretchers bonded together to form a portion which effectually overcomes the isolation of the rings and so effects a bond from intrados to extrados of the arch.

166. Straight Arch. This kind, also called a bonded arch, is shown in Fig. 49. It is called straight on account of the intrados and extrados being straight. This kind is sometimes called a bonded arch because the bricks are shown bonded on the face. As will be seen by the sketch the bricks are tapered, and in one half of the arch all the bricks are differently shaped. In consequence of this it is necessary to have the bricks specially moulded, or, if not, bricks have to be cut and rubbed down to the shape required. This kind of arch is well adapted for door and window openings, and they have a good appearance. An imitation of this form of arch is sometimes made by using the bricks in their ordinary state on an arch bar of wrought iron about 2¼ in. x ½ in., the want of taper being made up in the joint. Again the straight arch is sometimes built with bricks roughly cut to the taper required—the roughness of the edges being rendered partly unnoticeable by the pointing.

167. Semi-circular Arch. Fig. 54 illustrates an arch semi-circular in shape built in 4½ in. rings with ordinary bricks. This is a favourite form of arch, and is a very safe kind, for the tendency to spread is not as great as in the other kinds.

168. Segmental Arch. One of the most used forms of arch, namely, the segmental arch, is shown by Fig. 56. It, of course, takes its name from the curve of the soffit. This form of arch should only be used where the abutment is good, because (especially when the rise is small) the thrust makes a smaller angle with the horizontal than do those of the other kinds of arches.

169. Relieving Arch. This form of arch, as its name implies, is used to relieve girders and lintels of the weight of the superimposed walling. Fig. 55 shows two kinds. The half marked C is formed with stretchers and is the kind used when the jambs of a window opening are 4½ in. deep. That half marked B illustrates the kind used for wider window jambs, and also for all kinds of door openings. In all cases the arch should spring from the ends of the lintel or girder to be independent of shrinkage or any other change in the lintel. The brickwork (marked D) over the lintel (marked A) is called the core.

170. Other kinds of Arches include those which are *semi-elliptical, Gothic,* and *horse shoe* in form, the construction of

which is very similar to those just described, the chief difference being in the method of laying down the curve of form—a matter of geometrical knowledge.

171. Cornices and String Courses built with moulded and other special shaped bricks. In the olden days it was the custom to cut and rub the bricks which were specially prepared for the purpose to the particular shape required, and in some of the buildings standing to this day there are examples illustrating the greatest skill on the part of the workers in brick of those days, and also affording at the same time examples of very beautiful brick architecture, possessing a softness of colour effect that is not obtainable at the present day with our hard, machine-pressed bricks. But, however we may regret the loss of the artistic effect, it is impossible to be indifferent to the advantages which our bricks have when considered as to health as well as to durability. The fronts made of such soft bricks must have been damp, and nowadays they would not find favour. As mentioned in Art. 140 *ante*, the modern double-pressed bricks are so compact and hard as to be practically imperishable, so that all chance of cutting and rubbing is out of the question. The bricks for cornices, string courses, etc., are therefore moulded to the special shape required before they are burned, so that the surfaces are just the same as those of the plain bricks. A *Splay brick* is shown at A, Fig. 58. Splay bricks are used for tops of base courses, chimney stacks, cornices, etc. *Bull-nosed bricks* (one is shown at B, Fig. 58) are made for jambs of doors, cornices of buildings and parts of mouldings. A section of a small cornice composed of two courses of moulded and one course of plain bricks is shown by Fig. 57. The tops of all cornices and string courses should be weathered, that is, inclined downwards towards the outer edge, with cement, and in particular work at the top should be flashed with lead as at A, Fig. 57. In the case of ornamental fronts, some or all of the rings of the arches are built with bricks moulded on the outer ends.

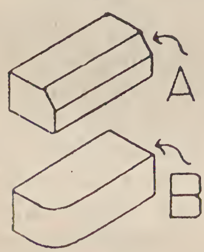


Fig. 58

172. Fireplaces and Flues. The arrangement of the flues from the various fireplaces in a house is a matter requiring skill and care, and is a most important part of the bricklayer's work, for, if badly designed or carelessly built, they are the cause of much discomfort and ill health. The sketch, Fig. 59, is intended to illustrate the various details connected with fireplaces and flues. Mostly the fireplace and its flue or flues

between the floor and ceiling of a room are contained in a projection which is called the "Chimney Breast"; and the small piers or parts of the breast which are on each side of the fireplace are called the "Jambs." In the sketch, Fig. 59, the space for the fire is shown, with an arch over it supported on an arch bar, which may be 2½ in. x ½ in. wrought iron. Fireplace arches are, however, sometimes built with a good rise; indeed often enough they are semi-circular in form and consequently do not need bars. As will be seen by the drawing, the opening above the fireplace is gradually diminished until it becomes of the same size as the flue proper. This part from the top of the fireplace to the flue is called the "Funnel" (marked D on the drawing). The oversailing of the brickwork to form the funnel produces what are called "Wings" (marked C and F on the drawing), the one that oversails the most (C on sketch) being called the "Gathering" wing. It will also be noticed that the funnel is not led directly into the flue, but is caused to bend towards one side first. This bend improves the flue by preventing down draughts. A bend just over the funnel is, however, only necessary when the fireplace is in the story just under the roof, for in the cases of those flues which come from lower fireplaces there are bends which, from a constructive point of view, are unavoidable, but which also serve the useful purpose of preventing down draughts. In the particular example given by Fig. 59, there are shown flues which lead from fireplaces in lower stories. These flues are brought up through the jambs and thence upwards as shown. Such is the general arrangement where fireplaces are one below the other (as they usually are) in the different stories of a building. The partitions between the flues are called

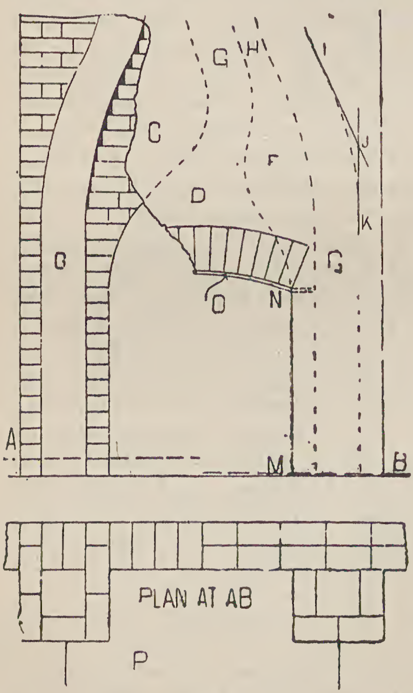


Fig. 59

"WITHES." (See H, Fig. 59.) It is essential to have the withes very carefully built to prevent any openings, however small, between the flues, for if there is any leakage of draught there will surely be a smoky flue. A portion of the front of the chimney breast, Fig. 59, is shown as removed, with a view of illustrating the way that the brickwork is built to form the various flues, etc. The bond is, of course, a matter which depends on the curves and number of the flues, so that the principle underlying it can be best described as the getting of as much tie or breaking of joints as possible. In ordinary work it is the custom to build the breasts with the space between the 4½ in. next to the outermost flue and the 4½ in. of the outer sides of the breast hollow, so producing what is called a "POCKET." It is, however, much better to build the breast solid. Each fireplace should have a separate flue, and the longer the flue the better the draught. It is to be remembered that the draught upwards in the flue is caused by the ascent of the heated air from above the fire, consequently it is important to prevent the ingress, over the fire, of more cold air than can be heated. In other words the flue will not act if too much space exists between the top of the fire and the head of fireplace. Neglect of this point has produced more smoky flues than any other cause. The outlet of the flue, that is, the top of the chimney stack, should be above the highest part of the building or nearby adjacent buildings. If not, the eddies produced by the walls or roofs will cause down draughts. Trees near to chimney stacks are very often the cause of smoky flues, for the same reason. Flues for ordinary room fires are 9 in. x 9 in. in cross section; but for large fires, as, for instance, those from kitchens, are made 14 in. x 9 in. Flues 14 in. x 4½ in. have been built, but the size (though allowing of a flat breast) is awkward. The bends in the flues should not be too sharp, but should be gradual and regular (see I J K, Fig. 59). Any angle under 130° is too low. During the building there is danger of the flues at the bends being made too narrow, so that special care is necessary at these places. It is a good plan to employ a chimney sweep to put his brushes through the flues prior to the taking over of the building from the builder, to discover in time any stoppages or defective bends.

173. Flues should be rendered with lime, or Portland cement, mortar and finished quite smooth; and, with a view to preventing damage by fire it is necessary to take care that timber or other inflammable material is not built in nearer than at least 4½ in. to the inside of the flue.

174. Hearths. The stone slabs about 6 in. thick, which were

at one time usually used for the hearths, or floors of fireplaces, are now almost entirely superseded by concrete. In the case of ground floor or basement fireplaces, the concrete is sometimes laid on a filling of stone spawls, which is kept in place by a brick hearth wall, and for those floors where such a method cannot be adopted as, for instance, upstair floors, the concrete is reinforced with steel. In common building the concrete is rendered on the top and trowelled off to a smooth finish, but in work of a first-class character the surface is generally formed with glazed hearth tiles, or face bricks, which admit of artistic treatment, and make a sound, imperishable top surface.

175. Essentials of Good Brickwork. To have good brickwork it is essential that the bricks shall be well shaped, and of proper size, that they shall be laid square with the face of the wall, and perfectly level, and also that the mortar joints shall be well filled and neither too thin nor too thick. If these conditions are fulfilled the joints will be regular, the courses will be horizontal, and the "perpends" will be well kept. Keeping the "perpends" means that similar joints of similar courses are arranged one above the other in perpendicular lines. The bricks should be perfectly rectangular in shape, while the size depends upon the thickness of the joint adopted. If cement mortar is being used the bricks must be well wetted before being laid in position. By reference to Art. 74 *ante*, it will be seen that joints about $\frac{1}{4}$ in. thick make (other things being equal) the strongest brickwork. The thickness of bricks is generally 3 in., but this is not of much consequence, the length and width being the dimensions which affect the bond. To have joints $\frac{1}{4}$ in. thick, the bricks should be 9 in. long and $4\frac{3}{8}$ in wide, as can be easily demonstrated by drawing, full size, a portion of a brick wall. If the joints are to be $\frac{3}{8}$ in. thick, the bricks will require to be 4 5/16 in. wide, and so on. The joints, both horizontal and vertical, should be well filled up with mortar. It is in this particular direction that most of the harm is occasioned by careless and unscrupulous bricklayers by their neglect to fill up the joints. A wall built with only the outside of the joints filled with mortar cannot be strong, nor proof against the weather, so that every attention should be given to the thorough filling of them. The best way to provide for the joints being well filled is to grout up each course with GROUT or liquefied mortar (see Art. 71 *ante*). There is, however, some objection to be raised against the use of grout on account of the weakening tendency of the water added for liquefaction. On this account many engineers and architects avoid using it, and ensure the joints being well filled with mortar from the trowel by constant supervision.

176. Finish of the Joints. Wherever the bricks are to be left exposed the joints should be "struck." This is generally done by running the trowel along the joint, pressing it smooth, and finishing it with a slight inclination downwards and outwards. Care should be taken that the inclination is not inwards, for, when finished in such a way there is a tendency to turn the rain water into the wall and dampness will result. The struck joint is much improved if the lower edge is cut off with the trowel. This is called a "struck and cut" joint. Raked joints are formed by raking out the mortar to a depth of about ¼ in. ironed joints are formed by the bricklayer "running" a rounded tool along the joint, leaving a half-rounded finish, as in the sketch at N, Fig. 60. Sometimes coloured joints are desired, and are formed by raking out the mortar and pointing the joints with coloured mortar. Of course, where the surfaces of walls are to be covered with plaster, or cement rendering, the joints are left rough, so as to afford a "key" for the plaster or cement. *Tuck pointing* is another way of finishing brickwork joints, and is done after the wall is built as follows: The mortar is raked out to a depth of about ¼ in., and the space is refilled with a mixture composed of cement and sand, coloured to match the tint of the bricks. This filling is made flat and flush with the face of the wall. The joints are then lined out with a narrow white line (about ⅛ in. wide) formed of lime putty. Tuck pointing, though generally adopted, is not to be recommended, for it is only too often made the means of covering up defective brickwork—the white lines being run over the faces of the bricks to remedy faulty "perpends," and ugly, thick joints are disguised by the filling, thus rendering bad work unnoticeable.

Coloured mortar is now available, and is frequently used in brickwork.

177. Thickness of Brick Walls. The following tables will be found to contain information regarding all ordinary cases of building, and may be followed with safety and economy.

TABLE XIX

Showing thickness of external and party walls of Dwelling Houses.

Height up to 100 ft.	Length up to 45 ft. One story . . . 27 in. Two stories . . . 22½ „ Three stories . . 18 „ Remainder . . . 13½ „	Length exceeding 45 ft. Wall to be increased in thickness in each of the stories below the uppermost two stories by 4½ in. (subject to provisions respecting distribution in piers).

TABLE XIX (*Continued*)

Showing thickness of external and party walls of dwelling Houses.

Height up to 90 ft.	Length up to 45 ft. One story . . . 27 in. Two stories . . . 22½ „ Three stories . . 18 „ Remainder . . . 13½ „	Length exceeding 45 ft. Same as above.
Height up to 80 ft.	Length up to 45 ft. One story . . . 22½ in. Two stories . . . 18 „ Remainder . . . 13½ „	Length exceeding 45 ft. Same as above.
Height up to 70 ft.	Length up to 45 ft. One story . . . 22½ in. Two stories . . . 18 „ Remainder . . . 13½ „	Length exceeding 45 ft. Same as above.
Height up to 60 ft.	Length up to 45 ft. Two stories . . . 18 in. Remainder . . . 13½ „	Length exceeding 45 ft. One story . . . 22 in. Two stories . . . 18 „ Remainder . . . 13½ „
Height up to 50 ft.	Length up to 30 ft. One story . . . 18 in. To below top-most story . . 13½ „ Remainder . . . 9 „	Length exceeding 45 ft. One story . . . 22 in. One Story . . . 18 „ Remainder . . . 13½ „
	Length up to 45 ft. Two stories . . . 18 in. Remainder . . . 13½ „	
Height up to 40 ft.	Length up to 35 ft. To below top-most story . . 13½ in. Remainder . . . 9 „	Length exceeding 35 ft. One story . . . 18 in. To below top-most story . . 13½ „ Remainder . . . 9 „
Height up to 30 ft.	To below top-most story . . 13½ in. Remainder . . . 9 „	
Height up to 25 ft.	Length up to 30 ft. If two stories . . 9 in. If more than two stories to below topmost story . 13½ „ Remainder . . . 9 „	Length exceeding 30 ft. To below top-most story . . 13½ in. Remainder . . . 9 „

If any story exceeds in height sixteen times the thickness prescribed for the walls of such story in the above table, the thickness of each external and party wall throughout such story should be increased to one sixteenth part of the height of the story; but such additional thickness may be confined to piers properly distributed, of which the collective widths amount to one-fourth part of the length of the wall.

TABLE XX

Showing thickness of walls of Public Buildings and Warehouses.

The thickness of walls at the top and for 16 feet below the top should be 13½ in., and the intermediate parts between base and such 16 feet built solid between straight lines on each side of wall from base to lower part of the top 16 feet. For walls not exceeding 30 feet in height the topmost story walls may be 9 in. thick.

Height up to 100 ft.	Length up to 45 ft. Base . . . . 27 in.	Length exceeding 45 ft. Wall to be increased in thickness from base to within 16 feet of the top by 4½ in., subject to provision respecting piers.
Height up to 90 ft.	Length up to 45 ft. Base . . . . 27 in.	Length exceeding 45 ft. Same as above.
Height up to 80 ft.	Length up to 45 ft. Base . . . . 22½ in.	Length exceeding 45 ft. Same as above.
Height up to 70 ft.	Length up to 45 ft. Base . . . . 22½ in.	Length exceeding 45 ft. Same as above.
Height up to 60 ft.	Length up to 45 ft. Base . . . . 22½ in.	Length exceeding 45 ft. Base . . . . 27 in.
Height up to 50 ft.	Length up to 30 ft. Base . . . . 18 in.	Length exceeding 45 ft. Base . . . . 27 in.
	Length up to 45 ft. Base . . . . 22½ in.	
Height up to 40 ft.	Length up to 35 ft. Base . . . . 13½ in.	Length exceeding 45 ft. Base . . . . 22½ in.
	Length up to 45 ft. Base . . . . 18 in.	
Height up to 30 ft.	Length up to 45 ft. Base . . . . 13½ in.	Length exceeding 45 ft. Base . . . . 18 in.
Height up to 25 ft.		Length unlimited. Base . . . . 13½ in.

If any story exceeds in height fourteen times the thickness prescribed for the walls of such story in the above table, the thickness of each external and party wall throughout such should be increased to one-fourteenth part of the height of the story; but such additional thickness may be confined to piers properly distributed, of which the collective widths amount to one-fourth of the length of the wall.

178. **Terra Cotta Blocks** are unglazed blocks 4 in. or 6 in.

thick, 12 in. x 12 in. in size, composed of clay burned in a kiln to a temperature of about 2,000° F. They are used for internal partition walls, for hollow block concrete floors, and as an insulation on top of concrete flat roofs. The blocks are light and are very useful for internal partition walls. See Fig. 59a, sketch C.

179. Terra Cotta Faience. See Fig. 59a, Sketches A and B. Terra Cotta, used as a facing to buildings, is manufactured from clay burned to a high temperature in a kiln, and has a glazed surface. The two main characteristics are its permanence and colour. The clays have to be selected for definite qualities and mixed in known quantities; they are ground up with a percentage of burnt clay (which tends to prevent the clay warping during burning), and mixed with water to a plastic mass. The clay is then stored to weather, after which it is pressed into moulds and then allowed to dry. After they are dry, the blocks are sprayed with the glaze and then burned in a kiln. As shown in Fig. 59a, the blocks are hollow, about 1½ in. thick, and particular care has to be taken in the manufacture to allow for the shrinkage that takes place. A wide range of colours is available.

When used as a facing the Terra Cotta blocks are backed usually with brick walls, the space between being filled with concrete (seven parts aggregate and sand to 1 of cement) or brickwork.

It is usual for the manufacturer to fix the blocks. Each block should be tied with two copper or galvanised iron cramps to the brickwork. The joints should be made with, and the blocks set in, cement mortar and pointed with Mastic putty. Fig. 59a, Sketch B, indicates to a larger scale how the Terra Cotta is fixed.

180. Wall and Floor Tiles. The best tiles are manufactured in England, but some are manufactured locally. There are two distinct processes in the tiles: the first being the preparation of the body, the shaping and the burning resulting in what is known as the biscuit, and the second, coating the biscuit with glaze and the final firing. The body is usually of clay, the result of decomposed granite—Silica and Alumina. The plastic clay is dried in ovens, then crushed to a dust which will bind under pressure. The dust is then formed into tiles in heavy presses, after which they are packed in fire clay boxes and burned in a kiln for ten days until a heat of 1,150° C. is reached. Five days is allowed for cooling. The glaze is applied as a liquid, and the tiles are burned in a gas-fired tunnel. The tiles are drawn through the tunnel on trucks. The standard sizes of wall tiles are 6 in. x 6 in., 6 in. x 3 in.,

and 4 in. x 4 in. Angle beads, round edge tiles, soap holders, etc., are available. Special floor tiles 4 in. x 4 in., 2 in. x 2 in., 2 in. x 1 in., 1 in. sq., 1 in. hexagon can be obtained. The average thickness of the tiles is ⅜ in.

The tiles are set in cement mortar, and those on walls should have at least 1 in. thickness of mortar behind them. The joints are sometimes pointed with Plaster of Paris.

180a. Terrazzo is made up of irregular fragments of marble in a matrix of cement. Used as a paving, it is laid *in situ* about 1¾ in. thick, and should be divided into panels by thin strips of metal such as brass to minimise the risk of cracking. Terrazzo is also extensively used as door treads and draining boards, when it is precast about 2 in. thick. Various colours are available by colouring the matrix and selecting the marble chips.

180b. Rubber Flooring is used as a covering on both timber and concrete floors, also stairs. It is obtainable as plain or variegated colours ⅛ in., 3/16ths in., and ¼ in. thick. Specially moulded treads are manufactured for stairs. The rubber is fixed with a solution which holds it in position.

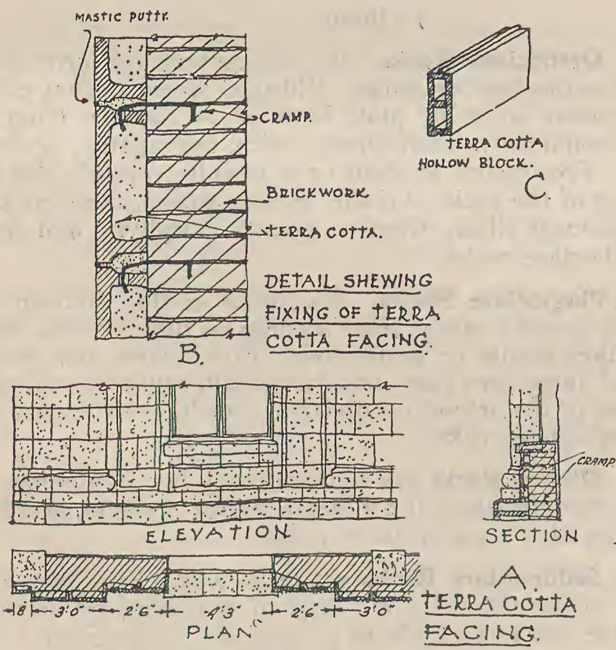


FIG. 59A

CHAPTER V

BUILDING STONES

181. Classification of Rocks. The rock formations from which the building stones are obtained may be classified under three heads, namely:—

(1) Igneous.
(2) Sedimentary.
(3) Metamorphic.

182. Igneous Rocks are those which have been forced up into or through the crust of the earth in a molten or plastic state by the action of heat. This group is divided into sections as follows:—

(a) Orthoclase Rocks.
(b) Plagioclase ,,
(c) Olivine ,,

183. Orthoclase Rocks. In this section the principal silicate is orthoclase or potash feldspar, which occurs either in its common white or pink form or as *sanidine* (that is, in glassy condition). Hornblende, mica, and apatite, occur commonly. Free quartz in blebs or in definite crystals also occurs in many of the rocks. Of the igneous group, these rocks contain the most silica. Granite, syenite, porphyry, and trachyte are orthoclase rocks.

184. Plagioclase Rocks. The rocks in this division of the igneous group contain some variety of lime or soda feldspar and either augite or hornblende. Free quartz also occurs in some of them, but they usually contain much less silica than do those of the orthoclase division. Basalt, dolerite, and diorite are plagioclase rocks.

185. Olivine Rocks are comparatively few in number. They consist principally of the mineral olivine. Augite, hornblende, and mica also occur in these rocks.

186. Sedimentary Rocks are those which have been formed by the deposition of some kind of sediment, or detritus, or from the remains of plants or animals. This group contains the largest number of rocks, many of which are of the greatest

value in building work. A feature of this class of rocks is that generally they are stratified. The group may be subdivided into three sections, viz.:—

(a) Fragmental or Clastic Rocks.
(b) Chemically Precipitated Rocks.
(c) Rocks formed by the remains of plants or animals.

187. Fragmental Rocks are formed in a mechanical manner from the detritus or sediment from the destruction of the older rocks. Conglomerate, breccia, sandstone, and greywacke are among those rocks which have been formed in such a way. The hard fragments are cemented together with a matrix, and a mass is produced ranging from a loose to a compact body, according to the hardness of the fragments and the quality of the cementing medium.

188. Chemically Precipated Rocks are formed by the precipitation of the mineral matter held in solution by water. Carbonate of lime, sulphate of lime, chloride of sodium, silica, carbonate of magnesia, and salts of iron are abundantly deposited in such a way. The oolitic, pisolitic, and travertine varieties of limestone, and also dolomite and gypsum have been formed by chemical precipitation.

189. Rocks formed by the remains of plants and animals. Very extensively accumulations have been, and are now being, formed of the remains of plants and animals. Owing to the fact that carbonate of lime is largely secreted by animals in their shells and skeletons, it forms the chief substance in rocks of organic origin. Chalk and crinoidal limestone are rocks formed from the remains of animals. The other rocks in this section (coal, for instance, which is a mineralised vegetation) are of no use in building work, and need no notice.

190. Metamorphic Rocks are those which have been changed from their original structure either by heat or by pressure or by both combined. The term is, however, generally applied to the recrystallisation which sedimentary rocks have undergone through the action of heat and pressure. Marble affords an example of this kind. Originally a limestone formed by organic agency or by precipitation, it has been changed into a crystalline structure by the action of heat and pressure due to igneous eruptions through it. The schistose rocks, such as gneiss and mica slate, are metamorphic, the schistose condition being brought about by enormous pressure and shearing. Clay slate is another rock which may be taken under the head of metamorphic, because, though originally a sedimentary rock, its structure has been changed to that of a fissile character by the action of pressure.

191. In the following articles will be found the various building stones described as regards the above classification, and with particulars as to physical qualities, from the builder's point of view.

GRANITE.

192. Granite, one of the igneous rocks of the orthoclase section, is a holo-crystalline compound of feldspar quartz and mica, the crystals of these minerals being in simple apposition, and large enough to be distinctly visible to the naked eye. The feldspar predominates and is mostly orthoclase, but sometimes feldspars of the plagioclase group are present. In colour the feldspathic crystals are either pink or some tint of red, but sometimes are pale grey, and rarely of a greenish tint. The quartz occurs in the form of colourless or grey crystals, and the mica in bright, glistening scales. The greater the quantity of quartz present the more durable will be the stone, but the presence of a large quantity of the quartz makes it very difficult to work. The feldspar crystals should be small and lustrous, for, if they are large and dull, they are likely to be decomposed, and consequently a source of great weakness. The mica is the weakest of the ingredients, and is very liable to decay. Many other minerals occur in small quantities. Of these iron is very dangerous if in combination with sulphur as pyrites, for decomposition is liable to take place and the sulphur set forth forms into sulphuric acid and destroys the stone. It requires considerable skill to judge as to the probable durability of a granite stone, but the leading points are as set out above, namely, the presence of a fairly large quantity of quartz, and small, lustrous crystals of feldspar.

193. Porphyritic Granite. Occasionally granite is found in which there are large crystals of feldspar embedded in the much less defined and smaller crystals of the other constituents. Rock of such a structure is called porphyritic granite.

194. Syenite is a holo-crystalline rock composed of orthoclase and hornblende, and is distinguished from granite on account of the absence (or almost so) of quartz and mica. As the crystals of the hornblende are black or dark green, syenite is of a dark colour, and is consequently not so pleasing as the true granite. In the case of orthoclase, quartz, mica, and hornblende all being present, the rock so formed is called syenitic granite. This latter kind is usually a dark, compact, and very durable rock.

195. True granite, syenite, and porphyritic granite, are popularly all classed as granite in ordinary building classification.

196. Granite, syenite, and porphyritic granite are very hard to work on account of their great hardness, and it is only in costly buildings that this can be used. These stones are best fitted for a massive style of architecture, where the walling surfaces may be left rough or rock-faced, and where the only dressed work is that of the plinths, columns, and other ornamental parts, which may be polished.

197. The following may be taken as representative of the chemical composition of granite and syenite. *Granite*: Silica 72·07, Alumina 14·81, Peroxide of Iron 2·22, Potash 5·11, Soda 2·79, Lime 1·63, Magnesia 0·33. *Syenite*: Silica 59·83, Alumina 16·85, Peroxide of Iron 7·01, Lime 4·43, Magnesia 2·61, Potash 6·57, Soda 2·44.

TRACHYTE.

198. Trachyte, one of the igneous rocks of the orthoclase division, is of a compact porphyritic structure, and is composed normally of sanidine (plagioclase sometimes being present) and hornblende, mica, augite, etc. The porphyritic crystals are usually of sanidine, while the matrix consists mainly of minute feldspar crystallites. In colour these rocks vary from grey and yellow to red brown tints.

199. Trachyte is found in all of the States, but is seldom quarried for building purposes. A rock very much like trachyte, but which, according to the Government geologist of New South Wales (who has made a careful investigation) is really a syenite, has been found at Bowral, N.S.W. This rock is known in the building trade as trachyte, and is a very good stone of a bluish grey colour. An analysis by the mineralogist of N.S.W. Mines Department, shows the constitution of this Bowral "Trachyte" to be as follows: Moisture at 100° o.c., 0·68; Combined water, 1·52; Silica, 57·14; Alumina, 16·13; Ferric Oxide, 4·69; Ferrous Oxide, 4·00; Manganous Oxide Trace, Lime, 3·44; Magnesia, 0·63; Potash, 5·07; Soda, 4·87; Phosphoric Acid, 0·25; Carbonic Acid, 1·42; Sulphuric Acid, 0·30; Chloride Sodium, 0·04.

200. The Composition, chemically, of Trachyte on the average is as follows: Silica 60·0, Alumina 17·0, Protoxide of Iron 8·0, Magnesia 1·0, Lime 3·5, Soda 4·0, Potash 5.0.

PORPHYRY.

201. Porphyry, also a rock of the orthoclase group, consists of large crystals of orthoclase interspersed throughout a matrix which is composed of quartz, and orthoclase intimately mixed.

202. The Porphyry Rocks are, as a rule, difficult to obtain in large blocks, and consequently are not generally much used in building work. The more beautiful kinds when polished have a fine appearance, and are greatly valued for such purposes as panels and shafts of small columns in architectural work.

BASALT, DOLERITE, DIORITE.

203. These Rocks are also of the igneous class, but of the plagioclase subsection. Basalt or bluestone is a dark compact homogenous rock composed of plagioclase, augite, magnetite, etc., the structure being such that the component minerals are too minute to be seen by the naked eye. The kind in which the grains of the constituent minerals are coarse or large enough to be visible without the use of a microscope is called dolerite. Diorite, or greenstone, is closely allied to the basalt, the main difference being that the mineral hornblende occurs in it and causes the greenish tint that is the characteristic feature in the appearance.

204. Like the Granites, the basalt rocks are very difficult to work, and consequently for masonry work they are costly. Again, on account of their sombre appearance, they are far from attractive, and are only suited for architectural work of a heavy style.

205. Basalt and Diorite are composed as follows: *Basalt*: Silica 45·00, Alumina 15·00, Magnesia 6·50, Lime 10·50, Soda 3·50, Potash 1·50, Oxide of Iron and Manganese 15·00. *Diorite*: Silica 53·20, Alumina 16·00, Potash 1·30, Soda 2·20, Lime 6·30, Magnesia 6·00, Oxides of Iron and Manganese 14.00.

SANDSTONE.

206. As pointed out in Art. 187, sandstone is a sedimentary rock of fragmental structure, the fragments being grains chiefly of quartz, but sometimes of a calcareous or argillaceous character. The cementing material or matrix may be either of a siliceous, calcareous, ferruginous or argillaceous nature. Mica, glauconite, and other minerals occur in proportionally small quantities in sandstones. According to the predominence of the particular mineral, sandstones are classified as follows:—

(a) Siliceous Sandstones.
(b) Calcareous ,,
(c) Argillaceous ,,

Those kinds in which the mica is in comparatively large quantities are called *Micaceous Sandstones.*

207. The best kinds are those which are composed of sharp,

clean grains of quartz cemented together with a siliceous matrix. Sandstones composed of grains of carbonate of lime and a siliceous matrix, or those with quartz grains and lime matrix, should stand fairly well, but, of course, would not, especially in town atmospheres, be nearly as durable as those of the imperishable quartz grains and siliceous matrix. Stones composed of argillaceous grains or matrix are liable to decay and disintegration, and are seldom used for building purposes.

208. Sandstones may be obtained perfectly white, or in colours, ranging from grey, yellow, brown, red, to dark blue. White stone shows absence of iron and other colouring minerals. Iron is the usual cause of the colour of sandstone. For instance, hydrated peroxide of iron being present causes various shades of yellow, while the different tints of red are caused by anhydrous peroxide of iron. Bluish colours are caused by phosphate of iron. Glauconite gives a greenish tint.

209. Sydney is surrounded with sandstone quarries, from which excellent building stone is obtained. The best known of all the quarries about Sydney are those at Bondi, from which a fine-grained and durable stone of even texture, which turns yellow on exposure, is obtained. Under the microscope a sample of this stone shows the grains to be clean and sharp, and the whole mass appears as bright and lustrous. This stone stands M. Brard's sulphate of soda test fairly well. There are also quarries at Waverley and Coogee, from which similar stone is obtained. Good stone is also quarried at various other places not far from the city. The chemical composition of Sydney sandstone is as follows: Moisture at 100° c., ·45; Combined water, 1.40; Silica, 87·60; Alumina, 8·53; Ferric Oxide, ·03; Ferrous Oxide, ·10; Lime, ·60; Magnesia, ·29; Potash, ·28; Soda, ·45; Sulphuric Acid, ·11; Phosphoric Acid Trace, Chloride of Sodium Trace, Soluble Silica, ·40.* The sample giving the above analysis was from Bondi. Specimens of excellent sandstones of more or less fine-grained texture from Hawkesbury, Maitland, Ravensfield, Rutherford, Clarence Town, Morpeth, and Paterson, in the Hunter River district, are exhibited in the Mineralogical Museum at Sydney. Sandstone suitable for building purposes is also obtained at Molong, Orange, Goulburn, Burrowa, Albury, Mudgee, etc.

210. Sandstone is a most useful stone for building purposes, not only because it is fairly easy to work, and if of good quality, is of a durable nature, but also because it is attractive in its appearance as plain walling, and is well suited for moulded and carved work.

* N.S.W. Mines Department, Annual Report, 1894.

BRECCIA CONGLOMERATE.

211. Breccia and Conglomerate rocks are, like sandstones, composed of pieces of older rocks held or bound together in a matrix; but the fragments are large—that is, larger than what would be called sand—hence the difference between these rocks and sandstone. When the fragments are angular in shape the rock is called *Breccia*. On the other hand, when the fragments are rounded like gravel or pebbles, the formation is known as *Conglomerate*. Both breccia and conglomerate rocks are useful for building purposes, though, of course, not nearly so useful as the various kinds of sandstone.

212. Breccia occurs generally in variegated colours, and where the fragments are of crystalline limestone it is polished as a marble.

Conglomerate (which, it may be noted, is sometimes called pudding stone) is called quartz-conglomerate, limestone-conglomerate, etc., as the character of the rounded fragments may be.

LIMESTONE.

213. Limestone is a sedimentary rock, composed chiefly of carbonate of lime, which has been formed either by chemical precipitation or from the remains of marine animals. Extensive limestone beds have been formed of the shells and skeletons of animals, and, according to geologists, most of the limestone has been formed in this way. Shelly or crinoidal limestone, when of a compact character, is valuable as a building stone. Many of the limestones of organic origin are, however, of a loose and crumbling nature, and quite unfitted for building work. The limestones formed by chemical precipitation are oolite, pisolite, travertine, gypsum, dolomite, and hydraulic limestone. *Oolite*, which is composed of very small, round grains, is a useful building stone. *Pisolite* is the name given to the stone when the grains are about the size of a pea. *Travertine* is a concretionary formation of the carbonate of lime. Pisolite and travertine are, like the oolite, very valuable as building stone. *Gypsum* (hydrated sulphate of calcium) and the *Hydraulic Limestone* (i.e., containing a certain amount of alumina) are used more for conversion into cements than for building stones (see Arts. 46 and 60), and need no notice under this head. The compact white and translucent variety of gypsum takes rank, however, as a rare building stone for use in ornamental work for interior decorations, and is known as *Alabaster*. *Dolomite* is a magnesium limestone composed of varying proportions of carbonate of lime and carbonate of

magnesia, and is a stone of durable quality and well fitted for building purposes.

214. **Limestones** are obtained from black to white, and in colours ranging from light cream to yellow, all shades of brown, grey, greenish grey, and blue.

215. **As a class** the limestones are valuable because they are fairly easy to work, are uniform in colour over any particular kind, and, if old world experience is to be taken into account, are capable of lasting a long time, even in city atmospheres. The best kinds are those which are dense and of homogeneous structure and of crystalline texture.

MARBLE.

216. **Marble** is a crystalline limestone found generally in the vicinity of igneous rock, though originally formed either by precipitation or from remains of animals. Its crystalline character has been caused by the action of heat or other agents of metamorphism, and, hence, may be put under the heading of metamorphic rocks. The name marble is, however, by no means devoted entirely to those limestones which are thoroughly crystalline in structure, for, as a general rule, the name is given to all limestones which are hard enough to take a polish. For beauty of appearance marble is quite unequalled, but being comparatively scarce (i.e., the more beautiful kinds) can be used only for the ornamental parts of buildings. Consequently, from a constructive point of view, marble has not the importance of the more abundant and generally-used building stones.

217. **Marble** may be obtained either pure white or white marked with veins, black, and in all shades and arrangements of colour. The most valuable, on account of the rarity of its occurrence, is the pure white, such as that from Carrara, which is used for statuary. This kind is composed of carbonate of lime, and has a crystalline texture like the finest loaf sugar. The veins, tints, and shades which produce the beautiful *figuring* of the coloured marbles are caused by the presence amongst the carbonate of lime, of minerals, such as iron, etc., in an oxidised state. The black appearance of some kinds is caused by the presence of bituminous matter.

218. **As pointed out** above, there are many kinds of coloured compact limestones and breccias, which, though not crystalline in structure, are capable of being polished. These stones are known as marbles. Of this kind is the encrinal or shell marble, composed of shell fossils, which give the characteristic markings.

219. The best white marble for statuary is obtained from Carrara (Italy), but a creamy white of great beauty, and by some preferred to Carrara, is obtained from Greece; this marble is called Parian. A white marble with dark veins called Silician, from Italy, is much used in all the Australian cities. Emperor's red is the name given to a very fine, red marble from Portugal. Sienna, obtained from Italy, is a yellow marble with veins, and is also largely imported into Australia. Rouge royal, obtained from both France and Belgium, is a beautiful red and brown marble with veins. Purbeck, from England, a marble much used by the mediæval builders, is a shelly marble of a grey colour. Paonazza, an Italian translucent white marble with dark veins, is a beautiful kind for interior work.

220. The Coloured Marbles are used mostly for veneer work in panels, etc., for interior decorations, but they are also much used for shafts of columns, balusters, and so on. Figured marble should not be carved, for the figuring or marking renders the carving useless by destroying the lines of ornament. It is the white marbles which are specially fitted for carving, as all the gradations of light and shade caused by the curved lines and surfaces are easily apparent in the spotless material. For this reason white marble is used for statuary, and for all kinds of work, such as capitals, which are enriched by carving.

SERPENTINE.

221. Serpentine is a massive compact rock of the metamorphic class, consisting of olivine and enstatite with, occasionally, glauconite. In colour it is generally dark green, with a beautiful figured surface when polished. This rock is used in the same way as marble for interior decorations. Some very fine kinds are obtained in the State—a rather light green kind, with vein-like figuring, from Bingara, in New South Wales, being specially beautiful.

SLATE.

222. Slate is a rock of argillaceous composition with laminated structure. According to geologists the laminæ or planes of slaty cleavage have been caused by great pressure during the lapse of time, and, though originally a sedimentary formation, may now be properly taken under the head of Metamorphic Rocks. The laminæ are not necessarily parallel to the planes of stratification—indeed, they generally make great angles therewith. Owing to the laminated or fissile structure the rock can with ease be split up into thin slabs or sheets. The better kinds of slate are much used for roof covering, for

which purpose the rock on account of its great hardness and resistance to water absorption is well suited. Slate is also used for door-steps, window-sills, nosings, pavement slabs, and for various sanitary fittings.

223. **Slate** may be obtained of different colours, such as red, purple, blue, green, yellow, and grey. As in the case of the other rocks, the colours are due to the presence of various metallic oxides.

224. **Large** quantities of slate are imported, the best amongst which are those from the Welsh quarries. Of the Welsh the best known are the purple and blue colours from Bangor, in Carnarvonshire. Green slates of good quality are also obtained from Westmorland, in England. A great quantity of blue slate comes from America, but it is of very poor quality. Some green slate (also from America), of which a lot has been used, is of better quality than the blue coloured, but yet are not nearly so good as the Welsh kinds. Although slate of very good quality is quarried in the Australian States, there has so far been very little used. The Castlemaine (Victoria) grey slate is a very hard and durable kind. At Bathurst (N.S.W.) a slate of a good quality is quarried. Slate is also obtained in Mintaro, in South Australia, and at Back Creek and Piper River, in Tasmania.

Localities of Various Australian Building Stones.

IGNEOUS GRANITE (Red).

N.S.W.: Albury, Burrinjuck, Braidwood, Bungendore, Bungonia, Broula Hills (Cowra), Carrick, Cooma, Cowra, Grenfell, Inverell, Jerangle, Jindabyne, Maffra, Mudgee, Mulloon Creek, Murrumbateman, Rylstone, Tarago, Tarana, Trial Bay, Wombeyan.

Victoria: Gabo Island.

Queensland: Gilbert Gold Field.

South Australia: Port Elliott.

GRANITE (Grey).

N.S.W.: Albury, Adelong, Arnprior, Bathurst, Braidwood, Breadalbane, Bredbo, Bungendore, Burrowa, Collingwood, Cooma, Cowra, Goulburn, Gunning, Harden, Inverell, Jerangle, Lake Bathurst, Montague Island, Moruya, Oberon, Tamworth, Tenterfield, Trial Bay, Tumut, Uralla, Yass, Young.

Victoria: Sandhurst, Harcourt.

Queensland: Ravenswood.

GNEISS.

N.S.W.: Bungendore (yellowish), Cooma (grey), Pomeroy (grey).

SYENITE.

N.S.W.: Bowral. (This stone is generally, but erroneously, called trachyte.)

VICTORIA: Gabo Island.

PORPHYRY (Various Colours).

N.S.W.: Bredbo, Burrowa, Canberra, Cowra, Currawong, Goulburn, Hall, Michelago, Murrumbateman, Uriarra, Yass.

QUEENSLAND: O'Connelltown (pink).

DIORITE.

N.S.W.: Bumbaldry, Goulburn, Jerangle, Tarago, Tumut, Wee Jasper.

BASALT.

N.S.W.: Dundas, Inverell, Jerangle, Kiama, Orange, Camden, Goulburn, Cooma, Jervis Bay, Mittagong, Liverpool, Bathurst, Parkes, Blayney, Nundle, Tamworth, Armidale, Lismore, Hill End, Wellington, Dubbo, Mudgee.

VICTORIA: Melbourne.

DOLERITE.

N.S.W.: Prospect.

SEDIMENTARY.

SANDSTONE (Fragmental).

N.S.W.: Albury, Clarence Town, Burrowa, Hawkesbury, Goulburn, Bundanoon, Maitland, Molong, Morpeth, Mudgee, Paterson, Orange, Ravensfield, Rutherford, Sydney (Bondi, Waverley, etc.).

VICTORIA: Darley, Geelong, Bacchus Marsh, Stawell, Barrabool Hills.

TASMANIA: Kangaroo Point, North West Bay.

QUEENSLAND: Brisbane, Grantham, Goodna, Helidon, Highfield, Murphy's Creek.

BRECCIA CONGLOMERATE.

N.S.W.: Bathurst.

LIMESTONES.

N.S.W.: Dubbo, Parkes, Orange, Cow Flat, Junee, Goulburn, Mudgee, Port Stephens, Bulli, Queanbeyan, Yass, Gundagai.

VICTORIA: Waurn Ponds, Portland, Warrnambool.

QUEENSLAND: Broken River, Gladstone, Ravenswood, Rockhampton.

SOUTH AUSTRALIA: Manoora, Mount Gambier District.

NEW ZEALAND: Oamaru.

METAMORPHIC.

SERPENTINE.

N.S.W.: Bingara.

SLATE.

N.S.W.: Bathurst.
VICTORIA: Castlemaine.
SOUTH AUSTRALIA: Mintaro.
TASMANIA: Back Creek, Piper River.

NEW SOUTH WALES MARBLES.

Arranged According to Colour.

MARBLES (Red to Yellow).

N.S.W.: (a) (Variegated) Bingara, Bucheroo, Bumbaldry, Burrowa, Caloola, Carroll, Coolalie, Fernbrook, Jeir, Limekilns, Marulan, Michelago, Molong, Mudgee, Parkes, Portland, Warialda.

(b) (Crinoidal) Kempsey, Michelago, Nemingha.

(c) (Brecciated) Attunga, Bingara. (Red) Borenore, Fernbrook.

GREEN.

Binalong, Queanbeyan.

BLACK.

Tarago, Windellama, Wee Jasper.

BLACK AND WHITE.

Orange, Rylstone, Springhill.
(Crinoidal) Bibbenluke, Gresford, Rockley.

WHITE AND STATUARY.

Abercrombie, Brundle Creek, Caloola, Cow Flat, Gilmore, Havilah, Michelago, Parkes, Wombeyan Caves.

BLUE AND GREY.

(Variegated) Bungonia, Cowra, Cudal, Michelago.
(Brecciated) Blue Borenore.

LAMINATED.

Adelong (Gilmore), Gilmore, Morongo, Queanbeyan, Tarrabandra.

OTHER AUSTRALIAN MARBLES.

QUEENSLAND: Ravenswood, Broken River, Gladstone, Rockhampton, Warwick.

SOUTH AUSTRALIA: Kapunda, Macclesfield.

225. Selection of Building Stones. In the selection of stone for building purposes, the matters to be considered are as follows:—

(1) Durability.
(2) Cost of obtaining and working.
(3) Appearance.

The matter of probable durability is, of course, the most important, though the question as to cost of obtaining and working cannot be disregarded; and, as a rule, both of these questions have to be considered as of weight in the selection. Appearance sometimes is important, but at all times looks must be of secondary importance to lasting qualities.

226. Causes of Destruction. Before dealing with the tests for the determination of probable durability, it will be necessary to notice the causes which tend to produce the decay or destruction of building stones. These causes may be set down as follows:—

(1) Rain.
(2) Wind.

(3) Variations of temperature.
(4) Vitiated atmosphere.
(5) Stresses.
(6) Wear and tear.
(7) Fire.

Rain, wind, and variation of temperature are natural causes of decay, and act separately as well as conjointly to bring about destruction. The rain-water gets in to a greater or lesser degree according as the stone is porous or compact, acts on the constituents, and changes their form, thereby producing disintegration. The wind helps by driving the rain in, and also acts separately by blowing dust and sand continually against the stone, thereby wearing it away. Change of temperature from hot to cold, if rapid, is injurious, causing, as it does, a too sudden contraction, which is followed by cracks. A reduction of temperature to freezing point has a disastrous effect on stone saturated with water, for the increase in bulk of the water owing to freezing causes rupture throughout the saturated parts. The impure atmosphere about all cities and manufacturing towns is most injurious to many kinds of stones, which contain ingredients liable to be attacked by acids. Constant wear in the building is a mode of destruction to which only some parts such as door-steps are subjected to. Transverse, compressive, and shearing stresses are within the control of the designer, and the stones should not be subjected to more than they can safely bear, which can be determined by experiment. Many of the building stones are quite unable to stand the temperature of ordinary fire. This is especially the case with some of the hard stones, such as granite, and there have been many serious collapses during the early stages of building fires owing to this unfortunate weakness.

227. The matter of most importance, as far as durability is concerned, is that the structure of the stone shall be of a favourable character. The composition may be good, but if the structure is such that the stone is loose and porous the quality of durability will be found wanting. The best structure is that of a thoroughly crystalline character, a fact which is well illustrated by Carrara marble, the composition of which is exactly the same as some of the loose and easily-destroyed limestones, yet, owing to its thoroughly crystalline structure, it is a most durable stone. It will be clear from what has been written above regarding destruction by rain-water that smallness of percentage of water absorption is of importance, for water saturation is bound to take place if the stone is loose or

porous. It is, however, to be noted that hard stones are not always the most durable, especially in some kinds of air, and under special conditions, such as obtain during fires. As opposed to wear by abrasion or in resistance to stresses, the heavier stones are, as a rule, the strongest.

228. Examination of Stone. The suitability of stone for building purposes may be determined by various methods of examination and by tests. The tests and kinds of examination used are as follows:—

(1) Microscopical examination.
(2) Field examination.
(3) Chemical analysis.
(4) Acid tests.
(5) Brard's sulphate of soda test.
(6) Percentage of water absorption test.
(7) Crushing, cross-breaking and shearing tests.
(8) Fire resistance tests.

The microscopical examination is of the greatest value, for, under the microscope the composition, condition, and combination of the ingredients, and the physical structure are all exhibited, so that a very reliable opinion may be formed as to the probable behaviour of the stone. Chemical analysis, though useful, is not nearly so good, for, although the kinds and several proportions of the various constituents are determined, no indication of the chemical combination is given. It is, of course, true that chemical analysis and miscroscopical examination can (at least with any degree of usefulness) only be made by those well versed in chemistry and petrology, consequently, these methods are not generally within the range of the architect or builder, Experienced chemists and petrologists are, however, always available, and their opinion should be obtained if little is known about the weathering qualities of the stone, especially if the work is important. An easy method of estimating the probable durability, and one which is within the range of all to make, is what may be called a field examination. This consists of visiting the quarry from which the stone is obtained, and making a careful examination of the effect of the weather upon the stone. In addition to the visit to the quarry, it will be well to visit the buildings in which the stone has been used, when a further examination may be made as to its weathering qualities. The value of the information so gained will, however, be very little if the weather and kind of atmosphere are different to that in which the stone is to be used.

229. Acid Tests are made on stones which are to be used in an impure atmosphere. These tests are made by applying a solution of hydrochloric, sulphuric or other acid, as the case may require, and carefully observing the effects. Stones containing carbonate of lime are acted on by hydrochloric acid—the action being indicated by an effervescence which is more or less brisk as the quantity of the carbonate of lime varies.

230. Brard's Test is really an imitation of the action of frost, the destructive effects of which have already been mentioned. The process of testing is as follows: A specimen of the stone is boiled for about half an hour in a saturated solution of sulphate of soda; the specimen is then immersed for about a couple of hours in a cold solution of the same chemical, after which it is suspended in a dry place. The stone becomes saturated more or less, according to the degree of porosity, with the solution of sulphate of soda which crystallises as it dries and increases in bulk with a corresponding tendency to split and disintegrate the stone. The quantity of stone detached or disintegrated is weighed, and the percentage which it is of the original weight of the specimen carefully determined. The greater the percentage of disintegration the poorer the quality of the stone.

231. Water Absorption. It will be clear from what has already been written regarding destruction by rain-water that smallness of percentage of water absorption is of the greatest importance, for water saturation will take place if the stone be loose or porous. The percentage of water absorption may be determined as follows: A specimen is carefully dried and weighed; it is then immersed in water for 24 hours, after which it is again weighed. The increase of weight is then found, and the percentage which the increase is on the original weight determined. The acid, water absorption, and Brard's tests are comparatively easy to carry out, and together serve to estimate the probable lasting power of a stone in a very reliable way.

232. The Compression Transverse and Shearing Tests should be made with proper testing machinery, and are only of value when made under the supervision of a competent testing engineer. For such works as piers, columns, lintels, corbels, etc., the loads to be borne should be carefully calculated, and a sufficient quantity of stone should be allowed to provide for a fair margin of safety. Rankine has suggested that the dead load should not be more than $\frac{1}{4}$, and the live load not more than $\frac{1}{8}$th, of the strength of the stone as determined by experiment.

TABLE XXI

Shows the crushing weight of some well-known Building Stones.

	Kind	Locality Where Obtained	Crushing Strength in lbs. per sq. inch	Percentage of Absorption	Remarks Average No. of Tests
1	Granite	Burrinjuck	15388	..	3
2	..	Gabo Island	15904	..	3
3	..	Moruya	14156	·418	3
4	..	Tenterfield	12577	..	2
5	Trachyte	Bowral	18569	..	3
6	Syenite	Gabo Island	25088	..	..
7	Basalt	Melbourne, Victoria	10908	1·153	..
8	Sandstone	Belmore	14022	..	3
9	..	Bundanoon	5667	..	3
10	..	Pyrmont	5420	2·970	3
11	..	Ravensfield	10707	..	2
12	..	Willoughby	3830	..	3
		Marrickville—			..
13	..	"Benson's" Quarry	4032	3·773	..
14	..	"Green's" ,, ...	5510	3·343	..
15	..	Waverley	4524	3·253	..
16	..	Parramatta	3046	3·497	..
17	..	Darley, Victoria	2118	..	..
18	..	Geelong, ,, ...	2150	..	..
19	..	Kangaroo Point, Tasmania	2956	..	..
20	..	North West Bay, ,,	2089	..	..
21	..	Adelaide, South Australia	2800	..	..
22	..	Brisbane, Queensland ..	1553	..	..
23	..	Bacchus Marsh, Victoria ..	1949	..	..
24	Marble	Attunga	10124	..	3
25	..	Warialda	4493	..	3
26	..	Caleula	16889	..	3
27	..	Kempsey	15933	..	3
28	..	Fernbrook	13949	..	3
29	..	Borenore	12349	..	3
30	..	Springhill	16732	..	1
31	Limestone	Warrnambool, Victoria ..	5035	..	..
32	..	Oamaru, New Zealand ..	4580	..	..
33	Slate	Mintaro, South Australia ..	19240	·564	..

Test 15 made by Prof. Warren at Sydney University. Tests 17 to 21 from a paper by Mr. J. G. Knight, read before the Victorian Institute of Architects. All other tests made by the author at the Sydney Technical College.

NOTE: All stones (unless otherwise stated) are of New South Wales.

CHAPTER VI

MASONRY

233. Seasoning of Stone. Stone should be seasoned by exposure in the air some time before being set in the walls of the building. The exposure causes the quarry water, or "sap," to be evaporated, and the stone becomes harder. It is best to have the stone worked up as soon after quarrying as possible, so that the increase of hardness may take place in the finished shape of the block. It is a great mistake to rework a stone, the face of which has been seasoned by exposure, for the increased hardness seems to be greater at the face, and the removal of the "skin" makes way for rapid decay. This being the case, it will be obvious that it is quite wrong to rechisel and rub down fronts of old stone buildings, as is sometimes done.

234. Position of Stone. Stones should be laid on their "natural beds," that is, they should be set with their layers of formation, or deposition, horizontal. Cornice stones are, however, an exception to the general rule, for they should be set with the laminæ, vertical. If horizontal, the layers of the projecting parts are likely to flake off. In the case of igneous rock the position is not of importance, on account of the absence of lamination.

235. Before describing the kinds of stone walls, it will be necessary to make clear the meaning of the following terms:—

"Scabbled" is the term given to the method of roughly finishing or dressing a stone with the axe, which is a kind of pick with chisel or axe-shaped cutting ends. "Axed" is a term given to the same kind of dressing as scabbling. "Quarry Faced" is the term for the faces of the stone left as when quarried. When the edges of the quarry face are struck off to a rough arris the face is called "pitched." A "draft" is a narrow, clean-chiselled band run round near the edges of a face or bed. "Clean chiselled" means that the face is chiselled down to a smooth surface. When the surface shows a series of clearly-worked furrows, left by the chisel, the work is called "Tooled."

236. Stone Walling may be divided into two classes as follows:—

(1) *Rubble.*
(2) *Ashlar.*

There are five kinds of rubble, namely:—

(a) *Random Rubble.*
(b) *Random Rubble built up in courses.*
(c) *Squared Rubble uncoursed.*
(d) *Squared Rubble built in courses.*
(e) *Coursed Rubble.*

237. Random Rubble consists of unhewn stones, of varying sizes, laid so as to fit between, and against, each other as well as possible, but without any attempt to arrange for courses.

238. Random Rubble Built up in Courses is composed of the same description of stones as the Random rubble, but, as shown at A, Fig. 60, the work is levelled up to horizontal joints at regular intervals up the wall.

239. In both of the kinds above mentioned it is necessary to provide a large number of stones long enough to extend through the wall, and to have them distributed as evenly as possible throughout the wall. There should be at least enough of these "headers" or "through" stones, as they are called, to have their ends make ¼th of the area of the face of the wall. Such headers are to provide for the requisite cross bond. A great deal depends upon the mortar; therefore, it should be of good quality; and care should be taken to have all joints and crevices filled, to make sure of which, it is as well to have the work "grouted up" at frequent intervals. The crevices between the larger stones should be filled with small pieces of stone as well, as with mortar, but it is only in such places that the small pieces may be used, for a wall composed of a large number of small pieces will be weak.

240. Squared Rubble Uncoursed. The stones for this kind of masonry are roughly squared, the beds are horizontal, and the joints are fairly uniform in thickness; but the courses are short, and vary in height. See B, Fig. 60. The remarks made above, as to the quantity of headers, applies equally to this kind of rubble wall. All kinds of rubble walls should have large, roughly-squared, or hewn corner stones, or "quoins," as shown at A and B, Fig. 60, to give the necessary extra stability at the angles. The pointing of the joints of rubble work should be done with cement mortar, the degree of finish of which, of course, will depend on the importance of the work, but it should always be done sufficiently well to keep rain-water out. The usual way is to tuckpoint it with cement, the tuckpointing line being about ½ in. wide.

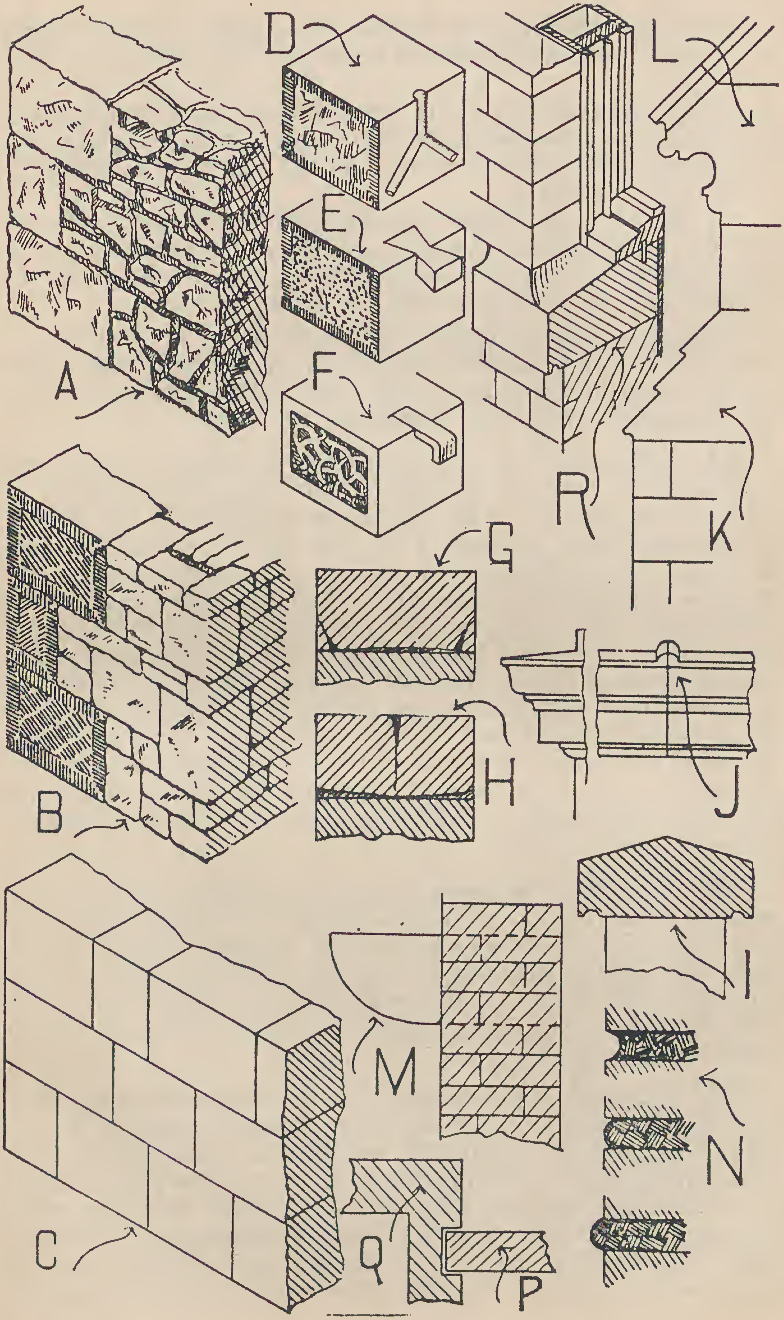


FIG. 60

Squared rubble built in courses is squared rubble brought to a level course throughout its length at every 10 to 14 inches in height.

In squared rubble straight vertical joints are often allowed, so long as they are not more than a foot or so in height, for uncoursed work, and not more than the height of a course in work built in courses.

"Coursed Header Work" is rubble similar to that shown in Fig. 60, except that the headers or bond stones are each of the full depth of the course in which they occur, the intervals between them being filled in with small stones.

Coursed rubble or regular coursed rubble, or "shoddies," consist of stones laid in courses, every stone in the same course being of the same height; the courses may, however, vary in height from 4 to 8 inches.

241. Ashlar consists of carefully-hewn blocks of stone, laid in courses of uniform thickness. An example of Ashlar is shown at C, Fig. 60. The blocks are fairly large, but should not be very long, because, if beyond a certain length, a tendency to break, transversely, arises. The safe length is put down by authorities as not more than five times the height, when good, hard stone is used. In Ashlar work the courses are usually 12 inches high, so that the longest stones are seldom beyond 5 feet, though, in first-class work where the beds are made with the utmost precision, this length is sometimes exceeded. It is not, however, necessary to have all the stones of the same length, for, provided the joints are broken, the stones may vary (see C, Fig. 60) up to the maximum adopted. The breadth of the stones should not be more than three times the height.

242. When the thickness of the wall is such that it is not possible to have every stone go through, it becomes necessary to provide for cross bond by having as many stones (if not right through) going as far into the wall from each face as possible. The joints of the best kind of Ashlar vary from 1/10 in. to ⅛ in., but there is a lot of Ashlar walling done with joints much thicker.

243. The greatest care must be taken, especially in the case of piers, to have the bed surfaces chiselled round near the edges and axed in the middle, so as to be perfectly fair and even throughout on every stone. If one of the bed surfaces is concave and allows a bearing at the edges only, the stone will split at the joint, causing what is known as a "flushed" joint. See G, Fig. 60, for an illustration of failure due to concave bed surface. On the other hand, if the bed surface

happens to be convex, and consequently bearing on the centre only, the stone is likely to split in the middle as shown by H, Fig. 60.

244. The outer surfaces of the stones for Ashlar work are finished in a variety of ways, the styles most generally adopted being the following:—

(1) Clean chiselled to a fair surface.

(2) Clean chiselled to a fair surface and rubbed quite smooth with stone and water. In addition to the last, the edges are sometimes elaborately moulded, and a panel worked on the face of each stone; sometimes a rebate is sunk on near its joint; this is called *"rusticated."*

(3) A margin *"draft,"* either clean chiselled, or tooled, varying from one inch upwards in width, is chiselled round the edges and the included part of the face left *"rock"* or "quarry" faced as at D, Fig. 60; or finished "sparrow picked," or "patent axed," as at E, Fig. 60; or "tooled" as at B, Fig. 60; or "vermiculated" as at F, Fig. 60. The methods of finish are, however, multitudinous, and combinations are adopted; for instance, the corner stones, or quoins, only, are often treated in an elaborate manner, and the surface of wall left with plain-faced blocks. For the inside, if the wall is to be plastered, the face is roughly dressed or "scabbled."

245. On account of the thinnest of the joints in Ashlar work, it is necessary to have the mortar quite free from coarse grit or pebbles. The mortar used should be composed of Portland cement and clean-sifted sand. The outer part of the joint, that is to about one inch from the face, is usually filled up with oil putty, the pointing thereof being like either one of the three sketches shown at N, Fig. 60, the middle one being the style which is most adopted. The vertical joints are "grouted up" and generally grooved for grouting. The grooving is formed by cutting a groove semi-circular in cross section, in the end of each stone. The groove branches into two or three as it gets towards the bed of the stone. These grooves are cut in each stone so that they will exactly coincide when the stones are placed end to end. When the stones are set, the groove is filled with cement mortar run in as grout. The groove joint greatly increases the strength of the wall, for, when set quite hard, the cement forms a stiff, intermediate body, in the form of a branch projecting into each stone, and

renders removal of either a matter of difficulty. A stone grooved at one end is shown at D, Fig. 60.

246. In the cases of towers and steeples, retaining walls, and other kind of masonry where great strength is required, it is usual to *dowel,* and *cramp,* or *joggle* the stones together. A dowel is a piece of metal, or hard stone, projecting into each of two adjacent stones. A cramp is a piece of metal shaped so as to extend over the joint, and into two adjacent stones with the object of holding them together. A joggle is shown at E, Fig. 60. Such a joggle would be made out of basalt or granite. A metal cramp is shown at F, Fig. 60. Cramps are generally made from 1 in. to 2 in. wide by from $\frac{1}{2}$ in. to $\frac{3}{4}$ in. thick, or $\frac{3}{4}$ in. diameter reinforcing rods, and 12 in. long. Iron should never be used for cramps or dowels unless well galvanised, for it will surely oxidise and split the stone. Copper and bronze are the best metals to use for cramps. The metal cramps are bedded and held in place firmly by cement, or else by brimstone, which is melted in a pot and run in hot. It was the general custom to use lead, which was run in a molten condition into the crevices, but, owing to the tendency of lead to be affected by atmospheric change, its use has been greatly curtailed. It is, however, still used a great deal. The joggles are held by cement run in as grout.

247. Ashlar Facing. In many cases it is too expensive to have the walls composed of Ashlar blocks throughout, and the facing only is of Ashlar, with the inner or back part composed of rubble or brickwork. With such work the most important matter is the question of cross bond between the facing and the backing. The cross bond is obtained by having plenty of headers from the Ashlar going well into the backing. Owing to the greater number of joints in the backing it has a tendency to settle more than the facing. Difference in settlement will cause cracks, and, consequently, unstable walling. With a view to minimising the difficulty, cement mortar should be used in the backing.

248. Block in Course. When the courses of stones are less than 12 in. deep, and when the work is of a rough (though not necessarily weak) character, the walling, instead of being called Ashlar, is known as "block in course."

249. The vertical joint between two walls of greatly different heights should not be made by bonding the stones of one into the other, for, on account of the greater number of mortar joints in the higher wall, it will settle most, and cracks will take place as a result of the unequal settlement. The best connection is to have one wall let into a vertical groove in the

other, as shown by plan at P Q, Fig. 60. In the sketch the wall P is shown as let into the wall Q, so that if Q settles more than P the movement may take place without destruction to either. The vertical joints between new and old walls should, also, always be made in this way.

250. Stone Footings. It was pointed out in Art. 24 *ante* that masonry is not as good as concrete for footings, nevertheless it often happens that masonry, if not altogether unavoidable, is, owing to circumstances of supply, the most convenient to use. Footings for very light walls may be composed of rubble masonry, but where the weight is at all considerable the stones should be in large blocks. The stones should also, if possible, be wide enough to allow of the bottom course being in single stones crosswise. In some cases where the walls are of great weight, it is impossible to have only one stone in the width of each course of the footings. More than one stone in the width necessitates careful bonding, and also that the courses shall be well bedded. For such work the stones should at least be roughly squared, but, if possible, the bed joints should be prepared with chisel draft and axed to a fair surface. The best kinds of stone to use for footings are granite, syenite, basalt, and the best of hard sandstone.

Base Course: A course of stone, generally about four or five courses of brickwork deep, is very often built in at about the level of the ground floor, in external brick walls, to mark the difference between the basement and upper walls.

251. Stone Cornices and string courses should be composed of long stones with their laminæ vertical and laid with very close vertical joints. In the best work it is usual to form a little ridge along each joint on the weathered top of the cornice. See Sketch J, Fig. 60. This method of top finish causes the water to be turned off quickly from the joint, thereby preventing the water soakage and consequent decay which take place when the cornice joints are wide and carelessly made. The ridge is small, being only about 1 in. high and 2 in wide. The exposed plane and curved surfaces of the cornices and string courses are finished either, clean chiselled only, or clean chiselled and rubbed smooth. Care should always be taken to so proportion the projection of the cornice that its weight will be fully counterbalanced by the superwalling or blocking course. In the case of crowning or pediment cornices having no blocking course or superwalling above, the overhanging part should be much lighter than the part resting on the wall. When the cornice is to be put on the side as well as front walls, care must be taken with the corner cornice stone. The cornice stones along the front of the wall

have projection from one side only, but the corner stone will have the projection from two sides; consequently, in a case where the cornice along the wall is just counterbalanced, the corner piece would be overweighted if not given extra superwall. The extra superweight is generally put in the form of some kind of corner ornament, such as a pedestal with urn or statue.

252. In case of cement stucco cornices or string courses, the inside or "core" of the projection is sometimes composed of stone roughly hewn to a shape somewhat smaller, but approximating to that of the finished cornice. The "cores" are set in the wall and the cement mouldings run on them.

253. Stone Copings should be built with stones as long as possible, for the fewer joints the better. In good work it is best to have the joints ridged at the top, as described for cornices in the last article. Sometimes the tops of the copings are rounded, sometimes sloped to one side only, and at other times sloped or weathered to both sides, as at I, Fig. 60. In no case should the coping be quite flat on the top. The coping should project on each side to effectually protect the wall. The projection is seldom less than 2 in., but may range from 1 in. upwards at the will of the designer. In all cases, the lower surface of the projection should have a groove called a "throat" run along it, as shown at I, Fig. 60. When inclined, as on a gable, the coping should be secured at the lowest point by a stone called a "kneeler" (see L, Fig. 60), which is built into the wall and makes a solid footing.

254. Door-steps should be in single stones and the quality should be of the hardest. Granite and basalt make excellent door-steps. Slate, in slabs about 2 in. thick, is also a good stone for the purpose, and is much used. In ordinary house building the kind most used is sandstone, but it is not able to stand the constant attrition and wears away very quickly. Door-steps are generally clean-chiselled on exposed surfaces, and in the case of sandstone the surfaces are occasionally rubbed fine. A more elaborate finish, such as nosing and mouldings, is often put on. The stones for door-steps should be at least 9 in. longer than the width of opening, so that there may be 4½ in. into the wall on each side. The ends of the steps, only, should be bedded, that is to say, the middle parts should not rest on the wall underneath. This is to prevent breaking, which is likely to occur should the parts of the wall on each side settle more than that under the door opening. If built in brickwork the thickness of the stone steps should be such as to correspond with some number of courses of

brickwork. *Approach steps,* like the door-steps, should always be of hard stone. If the door-step is to an external opening, it is often necessary to put in a water bar of copper or galvanised iron to exclude the weather. The bar is usually 1 in. x ¼ in. thick and is placed under the door.

255. Window Sills. The form of plain window sills generally used is shown at R, Fig. 60. This kind runs either 4½ in. or 9 in. into the wall on each side of the opening, and projects about 2 in. from the face of the wall, the under surface of the projection always being "throated" as shown. The top from the wood sill is "weathered" with a good slope downwards towards the front, while the projections of the ends are finished on the top with a scotia or splay. To make sure of keeping the water out, a water bar of galvanised iron or copper is put into the top of the sill and into the bottom of the wood sill as shown by the sketch, or the wood sill is rebated over the stone sill. As in the case of the door-steps, the sills should be bedded only at the ends. If the sills are to be used in brickwalling, the thickness should correspond with some numbers of the courses.

256. A Lintel is a stone beam spanning an opening and carrying the superimposed wall. When the span is beyond three or four feet, it is necessary to have a relieving or discharging arch built over the lintel. The arch is of stone or brickwork, as the wall above may happen to be, and is built on the same principle as a relieving arch. If the walling be brickwork the bearings of the lintel on each side of the opening should be either 4½ in., 9 in., or 13½ in., so as to suit the bond of the brickwork; while the height should agree with some number of the courses. Thin, column-like, vertical pieces of stone called "mullions" are often used to divide a large lintel-headed opening. In such cases care must be taken to avoid building the ends of the lintel into heavy pieces of walling, for the settlement of the piers and mullions will be unequal, and either the lintel will be broken, or the mullions crushed. Good, hard stone should be used for lintels, and if of laminated structure the layers should be vertical with the direction in the length of the lintel. A composite lintel is formed with three stones across the span, the centre stone being put in like a keystone in an arch.

257. A Corbel is a stone, or stones, projecting in the form of a bracket to support a weight such as a girder in the spring or an arch. A plain corbel is shown at M, Fig. 60. Corbels permit of treatment as architectural features, and, oftener than not, are moulded and carved in an elaborate manner.

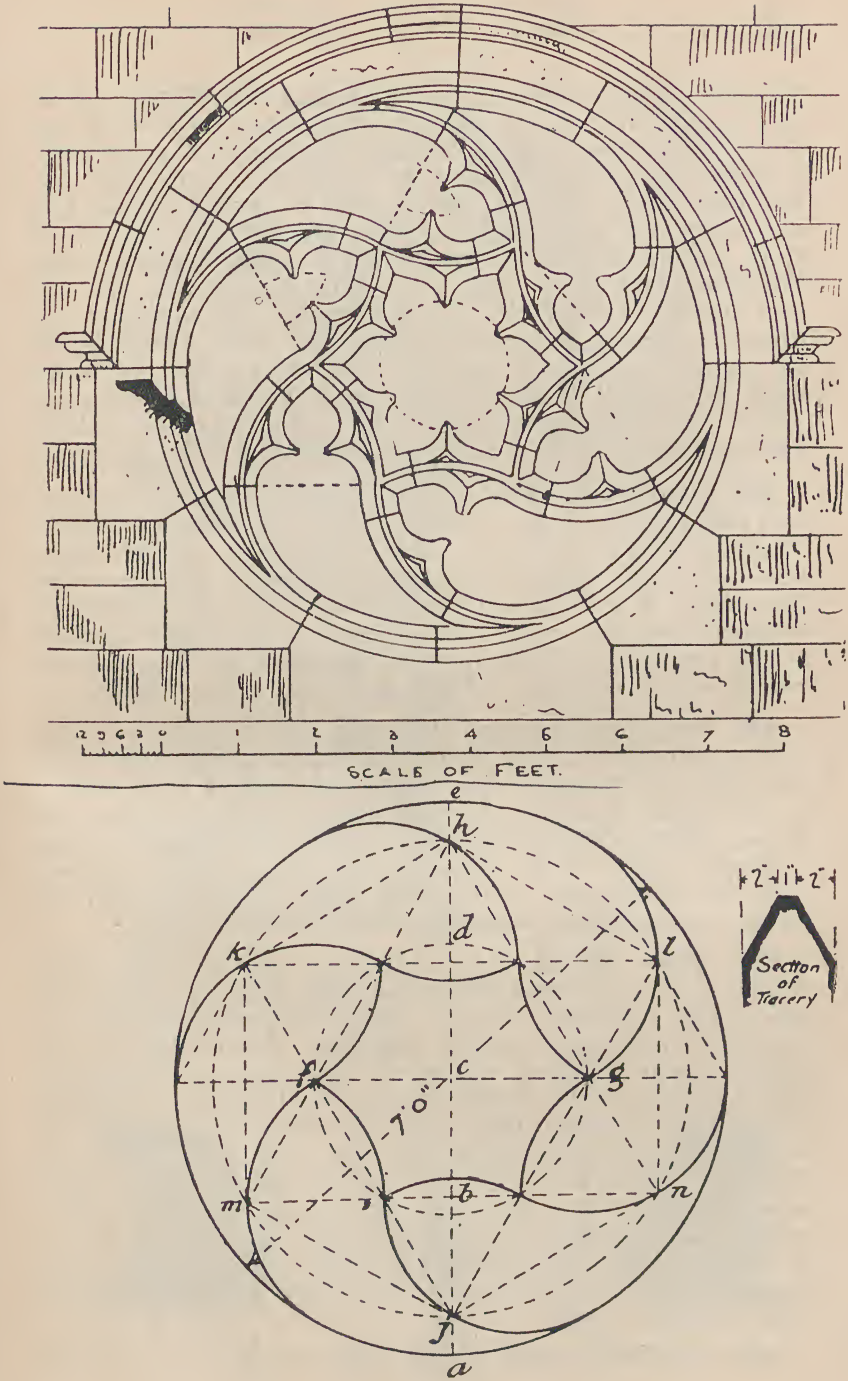
Constructively they should be strong enough to prevent being broken off by the weight upon them, and care should be taken that the top bearing surface is perfectly level, for, if the weight acts at the outer top corner of edge, breakage is more likely to occur.

258. Buttresses are projecting masses of masonry built at intervals along a wall to increase its strength. They are usually diminished in projection as the upper part of the wall is reached, and the parts at which the decrease in projection is made are sloped off, generally as shown at K, Fig. 60. To effectually serve their purpose the buttresses should be well bonded to the walls, and should have good foundations.

259. Masonry Arches are built on the same principles, and the terms used in connection with them are much the same, as described in the paragraphs on brick arches, the main difference being that the arch stones or voussoirs are all (unless in the very roughest rubble work) cut to the particular taper required. The outer edges or "drafts" of the joints should be very carefully clean chiselled, and the inner parts of the joint surfaces carefully axed, for, as the arch stones have to do, relatively, more important work than the stones in the walling, failure from "flushed" joint, or round joint surfaces, should be specially guarded against. All the joints should be grooved for grouting as described in Art. 245 *ante*.

260. Tracery. The stone used for the window decoration peculiar to Gothic architecture must be of a kind, such as sandstone, which can be easily worked, on account of the great amount of cutting and dressing necessary to produce the slender and gracefully curved moulded bars which form the *tracery*, as it is called. The various pieces to form the tracery should be very carefully jointed so as to avoid unsightly "kinks," or bulges. The "cusps" or triangular projections from the inner curves of the tracery should not make lesser angles than 60°, for, if less, the stone at these points will be too thin and will be rapidly decayed away. Figs. 61 and 62 are examples of stone tracery. The joints in the tracery should be strengthened with dowels, the dowels to be of trachyte, bluestone, or granite, about 1½ in. x 1½ in. x 4 in.

261. Stone Columns up to about 15 ft. in height are made with the shaft out of one piece of stone, but, when exceeding this height, they are usually built with the shaft in several pieces. There are, of course, cases where very tall columns have been made with the shafts as monoliths, but the great expense incurred is sufficient to prevent such being the general rule. The caps and bases are, in all but very small



12 9 6 3 0 1 2 3 4 5 6 7 8
SCALE OF FEET.
e
h
d
k
l
c
f
g
7' 0"
b
m
n
j
a
2" 1" 2"
Section of Tracery

FIG. 61

columns, made in separate pieces. Where the columns are to bear weight, it is of the greatest importance to have all the joints of bases and caps, and joints of shafts (if the shafts be in several pieces) made perfectly true and at right angles to the axes of the columns. In addition to perfect joints, it is also necessary to have the columns set with their axes vertical. Another matter to be attended to is the bearing of the lintel, or other part of the super-structure, on the caps, for care should be taken that the weight does not come on the *abacus*, or carving, but is borne by the solid part, which should be carried up about ½ in. above the *abacus*. Fig. 63 is an example of small quarter columns on each side of architraves. These columns are built up in courses. This figure also illustrates on a small scale the jointing of the stones in a pediment.

262. Template (or templet) stones are placed in a wall, or on a pier, under a girder or other beam to distribute the weight. They should always be of a hard, strong stone, and the thickness in all cases should be at least one-third of the narrowest dimension. A piece of lead, or leather, should be interposed between the under surface of the girder and the upper surface of the template, to mitigate the evil effects of irregularities which may be left after the dressing of the stone surface.

263. Protection of Stone Dressings. All the various parts of the stonework, such as door-steps, window sills, mouldings, and other ornamental work, should be cased in with timber, as soon after being set in position as possible, to prevent damage from falling material, and from the operation of the workmen. Care should, however, be taken that the timber used for the purpose will not stain the stone, as will, for instance, most of the Australian hardwoods.

263a. Stone Facing. As described in Art. 247 *ante*, stone can be used as a veneer to a brick wall. The days of the old solid stone building are past, except for such buildings as churches, museums, libraries, etc., and in its place is the modern frame building, where the floor loads are supported independently of the external walls. Such allows of thinner walls, where facing veneers may be used. An example of stone facing is indicated in Fig. 63a. The veneers vary in thickness from 2 in. to 6 in. for plain walling surfaces. Each stone must be tied to the brick wall at the back of it with a copper cramp from 6 in. to 12 in. in length and ⅜ in to 1 in. in diameter. The joints should be ⅛ in. thick, and the stones should be set in cement mortar. The joints should be pointed with a mastic putty.

263b. Synthetic Stone, as the name implies, is a precast

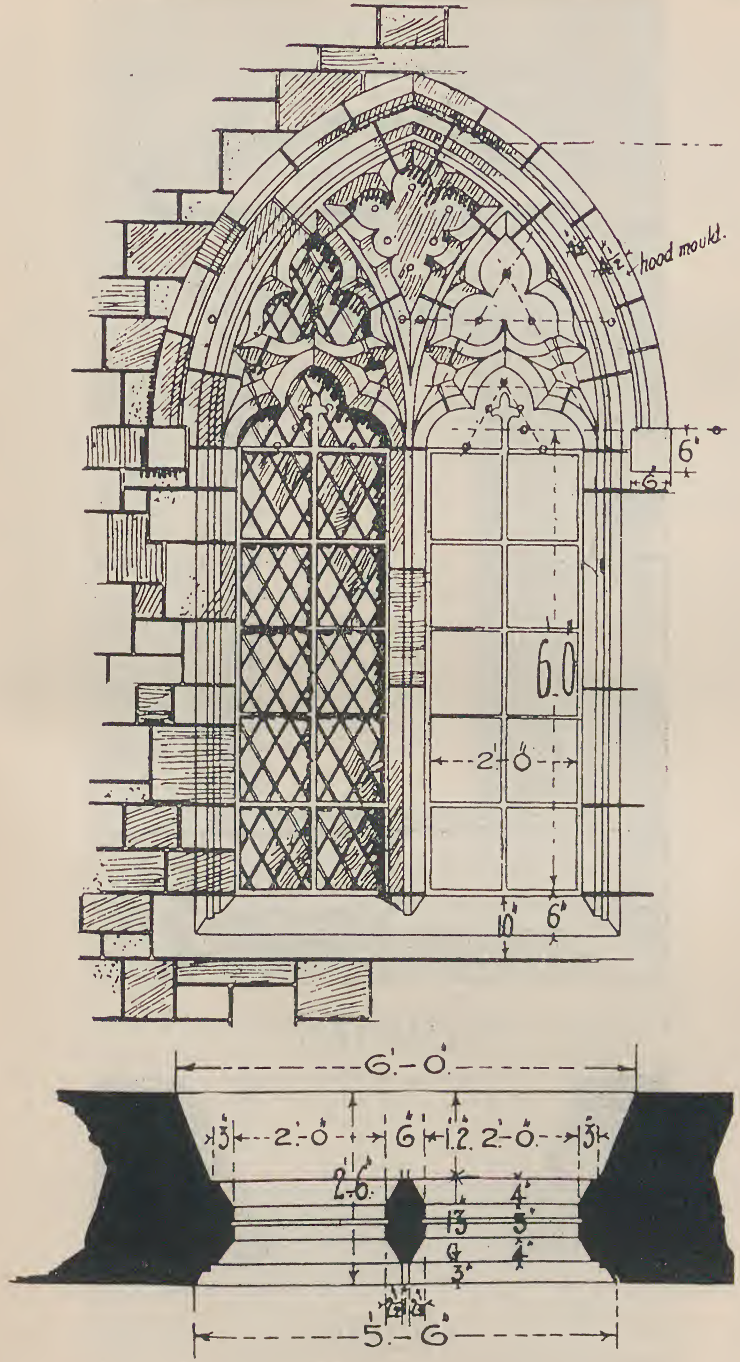


FIG. 62

L

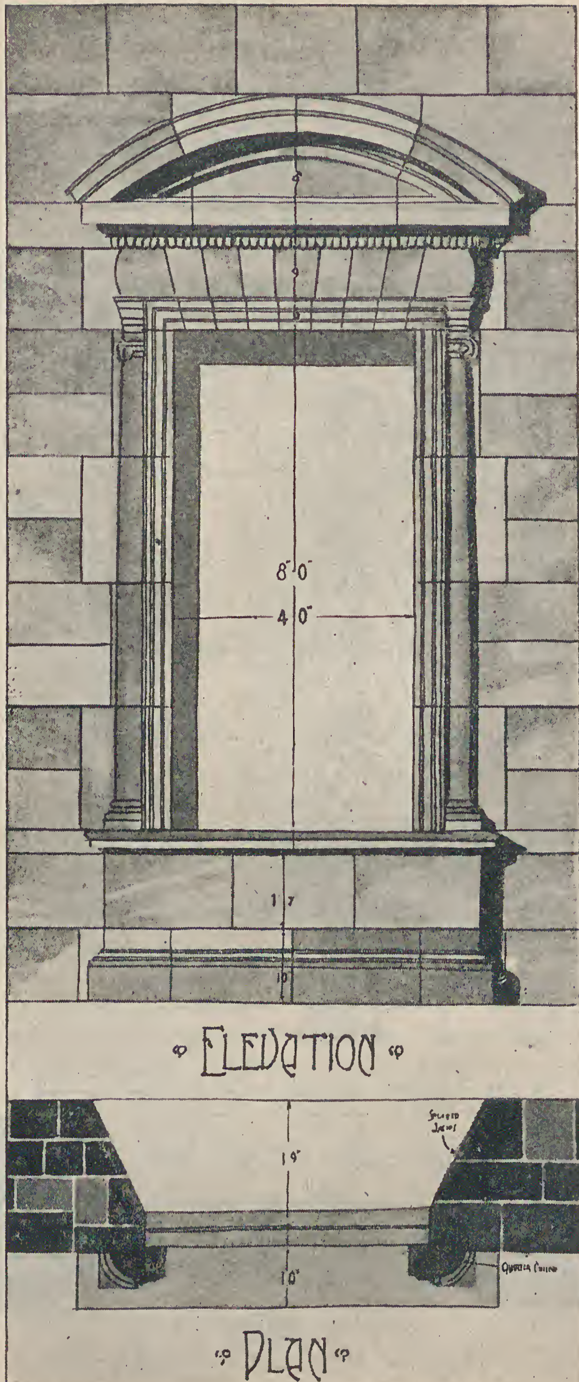


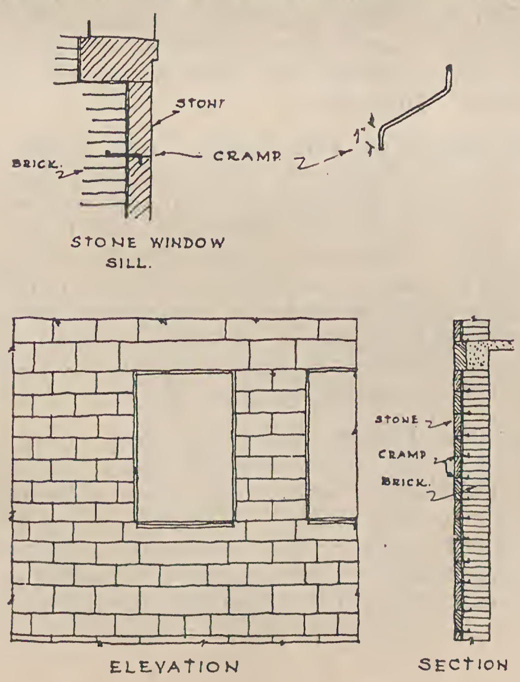
FIG. 63

stone, where natural stone is crushed to a suitable size and mixed with cement. The mixture is placed in a mould and allowed to set. It is manufactured by two methods: (1) where the facing material is comparatively thin and is backed with a mixture of stone chips and cement, and (2) where the facing material is cast solid for the full thickness. Colour is obtained either by the natural colour of the aggregate, or by using coloured cement. Synthetic stone is erected in the same way as described for stone facing in Art. 263a *ante*.

263c. Marble Veneers. As described in Arts. 216-220 *ante*, marble is generally used as a wall veneer, or as a paving. When used as a wall veneer the marble should be $\frac{3}{4}$ in. thick, and is fixed with dowels and cramps against plaster dabs. Behind the marble a space of $\frac{1}{2}$ in. is left void, to allow for the circulation of air and to prevent water and salts from the backing entering the marble. *Efflorescence* and loss of polish is likely to take place if the veneer is placed immediately against the backing.

When used as a paving the marble should be $\frac{3}{4}$ in. to 1 in. thick, and should be set in $\frac{1}{2}$ in. thickness of sand and cement.

In stairs marble treads should be $1\frac{1}{4}$ in. to $1\frac{1}{2}$ in. thick bedded solid in sand and cement. The risers are $\frac{3}{4}$ in. to 1 in. thick, and are fixed as for a wall veneer, but the space at the back should be filled with a weak mixture of sand and cement.



STONE FACING.

Fig. 63a

CHAPTER VII

BUILDING TIMBERS

264. Putting on one side the relative values of different timbers (these will be dealt with hereafter) and taking the matter of felling in a general sense, the most important points to be attended to are the suitable age of the tree and the best season for felling it.

265. The best age to fell a tree is when it has reached maturity, that is to say, when it has got to the age after which its growth ceases to improve it, for, although a tree does continue to grow after having arrived at maturity, the rate of growth is very slow, and is attended with decay, especially in the heartwood. On the other hand, if cut down too young there will be a large proportion of sapwood, and the heartwood will be wanting in hardness and density. Considerable experience is needed to judge with accuracy the time when maturity is just reached, but it is not difficult to distinguish when that condition has been passed, for the defects, such as heart decay, which inevitably occur, and the great decrease in the rate of growth are good indications.

266. Best Season to Fell Trees. Trees should be felled when the sap is not circulating, otherwise the timber got from them will be largely impregnated with sap, and will be sure to decay quickly. In tropical climates the sap is at rest in the dry season, while in temperate and cold places the winter is the time when the sap is down. It is difficult to lay down any hard and fast rule for guidance in this matter, on account of the overlapping of the climates, and the peculiarities of various districts. It is, however, a very safe rule to avoid cutting down a tree if it is sending out new shoots and leaves.

267. Seasoning Timber. Although every effort should be made to fell trees only at the time when they contain the least sap, it is impossible to find a time when a living tree will contain no juice or sap. Whatever there is of sap must be got rid of, for, if left in the timber, it becomes an active element of destruction, instead of, as originally, a means of nourishment, and a necessity of life. Moreover, if made into carpentry or joinery work, while in a "green" or juicy condition, much

trouble will be caused by its twisting and cracking. The expulsion of these juices is called *seasoning*, and is brought about by either natural or artificial means.

268. Natural Seasoning is carried on by exposing the timber in stacks, so that the air may get all round it, but it should be protected from the sun's rays, and from strong winds. The air dries the sap out, but the process is very slow, for it takes about four years of such exposure to fit a timber for joinery work. The Australian hardwoods behave very badly under the process of natural seasoning, for the expulsion of the sap by such means causes such large and numerous cracks, and so much twisting and warping, as to render a large percentage useless. It seems, therefore, that in the case of hardwoods at least, a system of artificial seasoning whereby the juices may be removed without cracking the timber, is greatly needed. For the sake, however, of expedition and thoroughness, there is much to be said in favour of artificial seasoning for all the timbers.

269. Artificial Seasoning consists of extracting, by some means, the sap more quickly and, perhaps, more thoroughly than can be done by natural seasoning. There are many methods of artificially seasoning timber and many have been tried with success. Several of the methods are as follows:—

(1) The timber is put into chambers and thoroughly steamed. Hot air is then injected into the chamber and the timber is well dried.

The following table * shows the results of the treatment by this method of some specimens of Australian hardwoods; judging from the great decrease in weight a large amount, if not all of the sap, must have been removed.

KIND	GREEN		SEASONED	
	Weight in lbs.	Size in inches	Weight in lbs.	Size in inches
Blackwood	110	$12\frac{1}{6}$ x 2	52	$11\frac{1}{2}$ x 1 15/16ths
Blue Gum	113	$10\frac{1}{4}$ x $2\frac{1}{8}$	84	$9\frac{7}{8}$ x $1\frac{7}{8}$
Stringy Bark ..	108	$10\frac{1}{4}$ x $2\frac{1}{8}$	82	$9\frac{7}{8}$ x $1\frac{7}{8}$

(2) Drying in hot air chambers without first steaming is often adopted, the air being heated to about 130°. The process is not as good as that above described, for the rapid action of the hot air is likely to crack the wood.

* From Proceedings of the Royal Society, N.S.W.

(3) Another method (described in "Rivington's Notes on Building Construction"), which is called McNeil's method, consists of treating the timber in chambers filled with moist air charged with certain gases evolved from the combustion of fuel under the chamber. This process, which is a patent one, is largely used in England, and it is claimed that the wood treated by it is rendered harder and tougher, and impervious to dry rot.

(4) Water seasoning consists of putting the timber under water for some time, until the sap is driven out after which the timber is dried in the air. Salt water is the best for the immersion, as it makes the timber harder and more durable, but has the drawback that it imparts to the timber the power of permanently attracting moisture. The timber should be fully submerged, for half under, and half out, of the water will do more harm than good.

(5) A process called "Powellizing" has lately become much used. It consists of boiling the timber in a saccharine solution.

270. Before passing on it is necessary to mention that some authorities on the subject contend that artificially seasoned timber is not so strong as that which has been naturally seasoned. If this be so, it is a matter still for debate as to whether the artificially seasoned is not even then the best on account of the improved chances of durability.

271. Selection of Good Timber. The best part of the trunk of the tree is the heartwood, for the outer part, under the bark, called the sapwood, is the newest wood and is loose and spongy. The timber should therefore be from the heart of the tree. It should be free from sap, or in other words thoroughly seasoned, and defects such as cracks, heartshakes (i.e., cracks radiating from the centre of the tree), cupshakes (i.e., circular cracks dividing the concentric layers of the wood) and gum veins. Knots should be avoided, unless the timber is selected for appearance, in which case the sound knots are often the centre of beautiful figures or markings.

272. Causes of the Decay and Destruction of Timber. The causes of decay and destruction of building timbers may be set down as follows:—

(1) Fermentation of sap, causing decomposition of the wood.

(2) Permanent dampness causing the development of wet rot.

(3) Want of ventilation causing the development of dry rot.
(4) Alternate conditions of wet and dry.
(5) White ants.
(6) Teredo.
(7) Fire.

273. The First Four Causes can with care and intelligence be easily avoided, for, if the timber is well seasoned there can be no trouble from fermentation of the sap, while permanent dampness or want of ventilation can, in house-building, exist only where there has been bad design or carelessness.

274. The Wet Rot is a decomposition under conditions of excessive and continuous moisture, while the dry rot follows upon exposure in closely-confined and ill-ventilated places. The latter is a disease in the form of a fungus which eats into the fibres of the timber and reduces them to the condition of a dry powdery dust.

275. White Ants. These insects abound in all parts of Australia, and destroy enormous quantities of timber annually. It is not at all uncommon to find cases where parts of buildings such as floors, roofs, and fittings are eaten away and rendered unsafe by these insects. They are very small, being not more than ¼ in. long, and a nest comprises millions of them. They eat away the wood from the inside without giving any outward indication of their presence. It is not certain that any kind of timber is exempt from their attack, though they attack the native timbers in preference to the imported kinds. There are many preparations in the market for coating timber to render it proof against them, but, if these washes are to be effective, care must be taken that the ants are not in the timber when supplied from the mill, for the solution may not penetrate right into the timber and their destructive action would be unchecked. The refuse from kerosene refineries called kerosene tar is good as a coating to guard against them, and will be rendered even more effective if arsenic be dissolved in it. When excavating the ground for the footings, etc., a search should be made for old stumps and such should be carefully removed, as oftener than not white ants are contained in them.

276. The Teredo is a marine worm which does much damage to timber submerged in or near salt water.

276a. The Borer. This is a pest which has become more intense during recent years. The most troublesome is the Powder Post Beetle. To guard against this kind sound hardwood timber should be used. Shot-hole borer attacks only when timber is seasoning.

CLASSIFICATION AND DESCRIPTION OF THE PRINCIPAL BUILDING TIMBERS USED IN AUSTRALIA

277. The Indigenous Timbers of Australia are of excellent quality, and plentiful, and they are freely used in all kinds of building work, but exotic timbers are also imported in large quantities and extensively used. A description of the building timbers, to be of use to the builder, must, therefore, include the imported as well as the native kinds.

For the sake, however, of clearness, the imported timbers are taken separately.

278. The following is a convenient practical classification of the various timbers:—

1. *Australian Hardwoods.*
2. *Australian Soft Woods and Figured Timbers.*
3. *Imported Hardwoods, Soft Woods and Figured Timbers.*
4. *Australian Pinewoods.*
5. *Imported* „

279. The Australian Hardwoods are of the genera Eucalyptus, Syncarpia, Angophora, etc. The timber is of a close texture, heavy, and very hard. Most of it is, however, subject to cylindrical splits, which are filled with kino, and when drying or seasoning these splits and cupshakes are developed. These defects arise from what may be called a remarkable feature of the trees of the Eucalyptus genus, namely, a tendency to split in concentric layers, rather than in planes, radiating from the pith or centre of the heart. The principal kinds are classified as follows:—

(1) *Ironbark of various kinds.*
(2) *Pale hardwoods.*
- (a) Blackbutt.
- (b) White Mahogany.
- (c) Tallow Wood.
- (d) Spotted Gum.
- (e) Grey Box.
- (f) Stringybarks.
- (g) Peppermints.
- (h) Brush Box.

(3) *Red Hardwoods.*
- (a) Red Mahogany.
- (b) Grey Gum.
- (c) Murray Red Gum.
- (d) Forest Red Gum.
- (e) Sydney Blue Gum.
- (f) Woollybutt.
- (g) Bloodwood.
- (h) Jarrah.
- (i) Karri.
- (j) Turpentine.

In the description which follows the genera and species, as well as vernacular names, are given.

280. Ironbark. There are five kinds of ironbark, namely:—

1. White or Grey Ironbark.		*Eucalyptus*	*paniculata.*
2. Narrow-leafed	,,	,,	*crebra.*
3. Broad ,,	,,	,,	*siderophloia.*
4. Red ,,	,,	,,	*sideroxylon.*
5. Silver ,,	,,	,,	*melanophloia.*

281. White Ironbark is the best of the five kinds, being the hardest and strongest. Obtained from Queensland, N.S.W., and Victoria.

282. Narrow-leafed and broad-leafed ironbarks are of a red colour, and are valuable timbers, though not so good as the white or grey ironbarks. The narrow-leafed species is found in the coastal districts of Queensland, and in N.S.W. as far south as Port Jackson; while the broad-leaf ironbark belongs to Southern Queensland, and N.S.W. from Port Jackson northwards.

283. Red Ironbark is deep red in colour. It is a good timber, though inferior to the three kinds before mentioned. It grows in Southern Queensland, N.S.W., Victoria, and South Australia.

284. Silver-leafed Ironbark is not valuable, the trees being small and stunted.

285. Taking the Ironbarks generally, they are unquestionably the best of the Australian hardwoods, being unequalled for strength in combination with durability. The timber may be distinguished by the texture, which much resembles that of horn, and a "gumminess" which is noticeable when planing it. It is difficult to work up to a smooth surface, for, unless a very sharp tool is used, it tears very much. Ironbark is principally used in building work for storey posts and beams, but it serves well for any work where hardwood may be used.

2.—PALE HARDWOODS

286. (a) Blackbutt. *Eucalyptus pilularis.*—This is a strong, durable timber, of a yellowish brown colour. It is generally straight grained, though at times it is found with a grain closely interlocked. Blackbutt grows in Victoria, New South Wales, and Southern Queensland. It is used for all kinds of house carpentry work.

287. (b) White Mahogany. *Eucalyptus acmenoides.*—This timber is of a yellowish colour, straight-grained, and is noted as being durable. Chiefly used for flooring-boards, slabs, rails,

and palings. It grows in South Australia, New South Wales, and Southern Queensland.

288. (c) **Tallow Wood.** *Eucalyptus microcorys.*—A timber of excellent quality, pale to dark yellow in colour, greasy in its nature, strong, durable, and easily worked. It is not so liable to shrink as the other hardwoods, whilst its distinguishing feature is its greasy nature above referred to. It is an excellent timber for storey posts, beams, joists, flooring-boards, door and window frames, sills, weatherboards, turnery, posts, rails, and indeed for building purposes generally. Though tallow wood is different to blackbutt and white mahogany, these latter timbers are often supplied where tallow wood has been wanted, for the three timbers are somewhat alike as regards general appearance. This substitution should be guarded against, for, although blackbutt and white mahogany are good timbers, they are not equal to tallow wood. Tallow wood grows in the northern coast districts of New South Wales and up to Cleveland Bay in Queensland.

289. (d) **Spotted Gum.** *Eucalyptus maculata.*—This timber is used extensively in building work. It is a light yellow-brown colour, with a close, wavy grain, very durable, and is tough, being particularly suitable for bending. *Eucalyptus maculata* grows in New South Wales and up to the centre of Queensland. It does not grow in Victoria, the spotted gum of that State being a species (viz., *Eucalyptus goniocalyx*) inferior in quality.

290. (e) **White or Grey Box.** *Eucalyptus hemiphloia.*—Of a whitish yellow colour, very heavy, hard, tough, and close-grained. It is not easily worked, but is suitable for posts, joists, rails, and other such work. Grey box grows in New South Wales, Victoria, South Australia, and southern Queensland. A report was submitted in 1896 to the Minister for Mines and Agriculture, N.S.W., by a committee appointed to inquire as to its value. The report, which has been published, contains means of information of a very valuable character, and, as a whole, favourable to the timber.

291. (f) **Stringy Barks.** *Eucalyptus capitellata, Eucalyptus macorrhyncha, Eucalyptus eugenioides and Eucalyptus obliqua.*—*E. capitellata* is a straight-grained, tough, durable, dark yellow-brown timber. It is generally called brown stringybark. It grows in Queensland, eastern Victoria, and New South Wales. *E. macrorrhyncha* is a stringy bark of New South Wales and Victoria. It is dark yellow and straight-grained. *E. eugenioides,* called "stringybark," white stringybark," and "broad-leafed stringybark," is a pale-coloured fissile timber which grows in

Victoria, New South Wales, and southern Queensland. *E. obliqua* is a very fissile timber, light to dark brown in colour, which is very much used for shingles, posts, rails, palings, etc. It grows in South Australia, Victoria, Tasmania, and southern New South Wales.

292. (g) Peppermint. *Eucalyptus piperita and Eucalyptus amygdalina.*—The former (*E. piperita*) is a durable timber which grows in Victoria, New South Wales, and Queensland. *E. amygdalina* grows in Victoria, Tasmania, New South Wales, and it is a durable, straight-grained, and comparatively light timber. Both of these species are used as a rule only for posts and rails, shingles, and such rough carpentry work.

293. Stringy Barks are often called peppermints, and *vice versa,* while peppermints are at times called *Messmate.* The timbers of these species are inferior to the other pale hardwoods mentioned in the preceding articles, and should not be used for other than rough building purposes.

294. (h) Brush Box. *Tristania conferta.*—This timber possesses toughness, strength and durability. It is of a grey-brown colour, and has an interlocked grain. Unless carefully seasoned, it splits and warps very badly. Brush box grows in northern Australia, Queensland and New South Wales.

3.—RED HARDWOODS

295. (a) Red Mahogany. *Eucalyptus resinifera.*—An excellent timber of a rich red colour, strong and durable, which becomes very hard with age. It resembles the American mahogany, but is of a different order. This timber is suitable for building purposes generally, but is mostly used for weatherboards. Red mahogany grows in New South Wales and Queensland. This timber has the reputation of resisting the cobra.

296. (b) Grey Gum. *Eucalyptus propinqua.*—A valuable red-coloured, close-grained, hard timber, which is very durable, and much resembles, though not so strong as, ironbark, for which it is often substituted. It grows in New South Wales and Queensland, and is used for all kinds of building work, but principally for posts, beams, joists, rafters, and shingles, frames, and fencing.

297. (c) Murray Red Gum. *Eucalyptus rostrata.*—A timber of a dark red colour, very hard, and consequently difficult to work, but very durable under the worst conditions, and is not destroyed by the teredo or by white ants. It can be used in building work to a great extent, but not generally, in places

where it would require to be worked up with smooth surfaces. It grows over the whole of eastern Australia.

298. (d) Forest Red Gum. *Eucalyptus tereticornis.*—This timber is closely related to the Murray red gum described in the preceding article. It is a heavy, close-grained, light to dark red coloured timber, which grows in Victoria, New South Wales and Queensland. It is useful for posts, beams, joists, rafters, frames, flooring and fencing.

299. (e) Sydney Blue Gum. *Eucalyptus saligna.*—A red-coloured, close, wavy-grained timber, which may be easily worked. This timber is suitable for posts, beams, joists, rafters, frames, sills, weatherboards, flooring, and such parts of building work. It grows in New South Wales and southern Queensland.

300. (f) Woollybutt. *Eucalyptus longifolia.*—A timber which is defective on account of gum veins, and as a consequence is not much used in building work. It can, however, be sometimes obtained in a sound condition, when it may be used for such purposes as posts, joists, rafters and rails. It grows in southern New South Wales and Victoria.

301. (g) Bloodwood. *Eucalyptus corymbosa.*—Like the woollybutt, this timber is subject to ugly gum veins, so that it is not of much value for building work. It is generally used for posts and rails. It is durable, and it is claimed that it can resist the white ants; while it has, excepting for the gum veins, a pleasing appearance when planed up to a smooth surface. It grows in southern Queensland and eastern New South Wales.

302. (h) Jarrah. *Eucalyptus marginata.*—This is a remarkably fine West Australian hardwood which, of late years, has attracted much attention. It is of a red colour (much like red mahogany in appearance) with a close texture and slightly wavy grain. It is easily worked to a smooth surface. Jarrah, though not as strong as some of the other Eucalypti, possesses the quality of durability in a high degree, and is able to withstand the teredo and white ant. It is suitable for posts, beams, joists, rafters, framing, weatherboards, shingles, flooring, turnery, etc.

303. (i) Karri. *Eucalyptus diversicolour.*—This is a light red-coloured, heavy, fairly straight-grained, tough timber. It does not work up easily, but is a useful timber for posts, beams, joists, rafters, and such parts of buildings. It grows in south Western Australia.

304. (j) Turpentine. *Syncarpia laurifolia.*—This is a dark, red-brown coloured timber, which is difficult to burn, is capable of resisting the teredo and white ant, and is durable under the worst conditions of damp. It is, however, liable to warp and twist very badly if not well seasoned. It is especially valuable for piles, but may be used, if well seasoned, for storey posts, beams, joists, rafters, frames, and such other parts of buildings. It is very slow to burn, which should be a recommendation for it as regards buildings. It grows in New South Wales and Queensland.

AUSTRALIAN SOFT AND FIGURED TIMBERS

305. The following are the most important of the soft and figured timbers of Australia:—

(a) Cedar.
(b) Rosewood.
(c) Red Bean.
(d) Onionwood.
(e) Colonial Beech.
(f) Blackwood.
(g) Myall.
(h) Black Bean.
(i) She Oak.
(j) Silky Oak.
(k) Red Silky Oak.
(l) Honeysuckle.
(m) Flindosa.
(n) Native Teak.
(o) Corkwood.
(p) Coachwood.
(q) Muskwood.
(r) Tulipwood.
(s) Maiden's Blush.
(t) Blueberry Ash.
(u) Red Ash.
(v) Queensland Maple.

306. (a) Cedar. *Cedrela Australis.*—This is a soft, but durable, red-coloured timber, beautifully figured, which much resembles mahogany, and has to an eminent degree all the qualities to fit it for use in the best kinds of joinery and cabinet work. It grows in New South Wales and Queensland, but owing to indiscriminate use, and large waste in the past, it is not very plentiful. It is used in first-class work for jambs and doors, window frames and sashes, architraves, skirting, staircases, show cases, counters and other such internal fittings. It is the very best timber for the plugs used in joinery work to afford nail hold in the walls.

307. (b) Rosewood. *Dysoxylon fraserianum.*—A medium soft, red-coloured timber, which, like the cedar, also resembles mahogany. It is of excellent quality, and being plentiful can be cheaply obtained. It can be used for all kinds of joinery and cabinet work, and is a good substitute for cedar. It grows in Queensland and northern New South Wales.

308. (c) Red Bean. *Dysoxylon muelleri.*—This is another red-coloured timber which is valuable for joinery work. It

is very like rosewood in appearance and quality. It grows, but not plentifully, in northern New South Wales and Queensland.

309. (d) Onionwood. *Owenia cepiodora.*—This timber is like cedar as far as texture is concerned, but is of a different colour, being a light yellowish red. It is useful for all kinds of joinery work.

310. (e) Colonial Beech. *Gmelina leichhardtii.*—This is a very light yellow-coloured, soft, but close-grained and exceedingly durable timber which does not warp. It is principally used for flooring, but it is of sufficient value to admit of its use in all kinds of joinery work, although it is plain in appearance. Colonial beech grows in Queensland and New South Wales.

311. (f) Blackwood. *Acacia melanoxylon.*—This timber is exceedingly valuable for the best kinds of house fittings and cabinet work. It is very hard and has a dense texture with a very pretty figure, and resembles American walnut. Unless very carefully seasoned it warps rather badly. The best comes from Tasmania, but it also grows in South Australia, Victoria, and New South Wales.

312. (g) Myall. *Acacia pendula* and brigalow *acacia harpophylla* are hard, heavy, dark-coloured timbers, which are principally used for turnery work. They are obtained from New South Wales and Queensland.

313. (h) Black Bean. *Castanospermum Australe.*—A figured brown-coloured timber, which is fairly hard, and somewhat like blackwood in general appearance. This timber is principally used for cabinet work, but could be used for many kinds of joinery work. It grows in northern New South Wales and Queensland.

314. (i) She Oak. Forest oak, swamp oak. *Casuarina of various species.* These timbers are hard and durable, and, though like the oaks described in the following articles, not of the same genus as the English oak, they are much like that famous timber in grain. They are generally of a red colour. These oaks make splendid shingles.

315. (j) Silky Oak. *Grevillea robusta.*—A hard, buff-coloured timber very like English oak, though not of the same genus. It is elastic, strong and durable and well fitted for joinery work. Silky oak grows in New South Wales and Queensland.

316. (k) Red Silky Oak. Sometimes called beefwood. *Stenocarpus salignus.*—This is a red-coloured timber with a

peculiar uniformly undulating figure. It is a hard timber, but not difficult to work, and is suitable for cabinet work and for panels, etc., in joinery work. Red silky oak grows in New South Wales and Queensland.

317. (l) Honeysuckle. *Banksia serrata.*—A handsome timber of a red colour, with a grain somewhat like English beech. It is hard and fairly durable, but requires to be very carefully seasoned. Honeysuckle grows in Tasmania, Victoria, New South Wales and Queensland.

318. (m) Flindosa. *Flindersia Australis*, and (n) Native Teak. *Flindersia*—Flindosa is a very hard, close-grained timber of great strength. It is of a pale colour and resembles colonial beech, for which it is often substituted. Flindosa (or cudgerie, as it is sometimes called) is generally useful in building work. Native teak is a hard timber which is difficult to work, but very durable. These timbers grow in New South Wales and Queensland.

319. (o) Corkwood. *Ackama muelleri* (p) Coachwood. *Ceratopetalum apetalum.*—These timbers are of a light colour, exceedingly tough, and very suitable for joinery work. They grow in New South Wales.

320. (q) Muskwood. *Oleoria argophylla.*—This timber takes its name from its pleasing fragrance. It has a pretty, mottled appearance and is suitable for panels and such work. Obtained from New South Wales, Victoria and Tasmania.

321. (r) Tulipwood. *Harpullia pendula.*—A close-grained, pretty timber, in shades from yellow to black. It is suitable for panels. Grows in New South Wales and Queensland.

322. (s) Maiden's Blush. *Echinocarpus Australis.*—A timber of a light yellowish-brown colour, very soft, but durable, and chiefly used for ornamental purposes. Grows in New South Wales and Queensland.

323. (t) Blueberry Ash. *Elaeocarpus cyaneus.*—This is a dark-coloured, tough timber, which, in quality, resembles English ash. It grows in New South Wales, Victoria, Queensland and Tasmania.

324. (u) Red Ash. *Alphitonia excelsa.*—This timber is sometimes called mountain ash. It is close-grained, hard, and durable, and is tough. It is suitable for building purposes generally. Red ash grows in New South Wales and Queensland.

324a. (v) Queensland Maple. *Flindersia chatawaiana.*—This valuable timber has come into use for fittings and furniture, and in a measure is a good substitute for cedar. It is a light-reddish brown in colour, with a beautiful grain. It can be obtained in large sizes.

IMPORTED HARDWOODS AND FIGURED TIMBERS

325. The most important of these timbers are as follows:—

(1) Oak.
(2) Mahogany.
(3) Ash.
(4) Elm.
(5) Teak.
(6) Beech.
(7) Walnut.
(8) Rosewood.
(9) Maple.

There are other timbers such as hickory, box, lignum vitæ, willow, yew, etc., which are imported in small quantities for special purposes, but not in connection with building; hence they are not dealt with here.

English and foreign hardwoods and figured timbers are not regularly kept by Australian timber merchants, as the cost of landing them precludes their use in other than first-class buildings, and then only in the best of the joinery and cabinet work. They may, however, be imported as occasion demands.

326. (1) Oak. This timber grows in various parts of Europe and America. The kinds known to commerce are as follows:—

(a) English Oak.
(b) Bay Oak.
(c) Durmast Oak.
(d) American Oak.

327. (a) English Oak. *Quercus pedunculata.*—This is the best kind of oak, being exceedingly strong and durable, with a straight and fine grain, its colour being brownish-yellow.

328. (b) Bay Oak. *Quercus sessiliflora.*—A timber almost of the same quality as English oak, but it is less dense and is liable to warp.

329. (c) Durmast Oak. *Quercus pubescens.*—This kind is not so good as the two mentioned above.

330. (d) American Oak. *Quercus alba.*—This oak, though not so good as the English kinds, is a tough, durable timber of a whitish-brown colour, with a reddish tinge, the grain being coarse and straight.

331. Oak is noted as being a very durable timber of great strength and possessing a pleasing appearance. However, as before noted, it is only possible to use it here for internal fittings, for which it is very suitable. The timber is sold in the

English market in logs from 10 to 16 inches square, and from 18 to 30 feet long, and in planks from 2 to 8 inches thick, from 9 to 13 inches wide, and from 24 to 35 feet long. The American oak is sold in logs from 12 to 24 inches in thickness by from 25 to 40 feet long.

332. (2) Mahogany. *Swietenia mahogani.*—This well-known timber grows in America and the West Indies. That known as "Honduras mahogany" grows in the country surrounding the Bay of Honduras, and also in Brazil; whilst that called "Spanish mahogany" grows in Cuba and other islands of the West Indies. Honduras mahogany is straight-grained as a rule, and is of a red-brown colour. It is sold in the English market in logs 2 to 4 feet square by from 12 to 14 feet long. Spanish mahogany is the best as far as appearance is concerned, for it has a beautiful wavy grain. Spanish mahogany is sold in the English market in logs 11 to 24 inches square by from 18 to 35 feet long. This timber is used occasionally for internal fittings but Australian people know it mostly as a furniture timber.

333. (3) Ash. *Fraxinus excelsior.*—A durable, tough, and very elastic timber, easily worked, and of a brownish white colour. It is used in small quantities in good joinery work. Ash grows in Europe, Asia and America.

334. (4) Elm. *Ulmus campestris.*—This is a strong, durable timber, of a reddish-brown colour, very cross-grained and difficult to work. It is used in the old countries in positions subject to permanent wet.

335. (5) Teak. *Tectona grandis.*—An excellent timber with a straight-grain, possessing great strength, and is of great value in construction. It is somewhat like oak, but darker, the colour being brown. It is sold in the English market in logs from 10 to 30 inches square and from 20 to 40 feet long. It grows in southern Asia.

336. (6) Beech. *Fagus sylvatia.*—A hard, compact, fine-grained timber, very tough, but not difficult to work. It is not used much in building construction, but is a notable timber to builders on account of the extensive use of it in all kinds of wood-working tools. In cabinet work it looks well.

337. (7) Walnut. The two species best known to commerce are common walnut, *Juglans regia*, and black walnut, *Juglans nigra*. The former is found in Europe. It is a solid, compact, wavy-grained timber, which does not twist or warp. Black walnut is an American timber, very beautiful in appearance,

the colour being dark purple or violet, which, however, becomes very dark as the timber ages. These timbers are expensive, and are only used in cabinet work.

338. **(8) Rosewood** (*Dalbergia nigra*) is a timber obtained from Rio, Bahia, Jamaica, and Honduras. It is of a deep, ruddy-brown colour, richly streaked, and grained with black, resinous layers, and takes a fine polish, but it is somewhat difficult to work on account of its resinous nature. It is sold in half-round logs 5 to 12 inches at thickest parts by from 10 to 20 feet long. The use of rosewood is confined to cabinet work.

339. **(9) Maple.** Common maple, *Acer campestri*, and birds' eye maple. *Acer saccharinum.* Common maple is a European species of a whitish-yellow colour, and very fine grain. Birds' eye maple grows in America. It has a pretty appearance, being studded at intervals with small, brilliant-looking knots, and the timber itself is of a whitish colour, which turns to a rosy tinge on exposure to light. Maple is much prized for making into small pieces of cabinet work, and for inlaying, panels, etc., in joinery work.

AUSTRALIAN PINEWOODS

340. **The following** are those in use as building timbers:—

(1) Colonial Pine.
(2) Cypress Pine.
(3) Huon Pine.
(4) Brown Pine.

Kauri pine does grow in small quantities in Queensland, but what is used here is obtained from New Zealand, hence it will be taken under the head of "Imported Pine Woods."

341. **(1) Colonial Pine.** *Araucaria Cunninghamii.*—This timber is known in different places as "colonial pine." Morton Bay pine, Richmond River pine, and "hoop pine." It is of a pale yellowish colour, is easily worked up and is durable if kept free from moisture. It is studded sparsely with very small, round knots, which give it, when planed up, the appearance of birds' eye maple. Colonial pine is used (especially in country places) for all kinds of building work, but more especially for flooring and lining boards, window frames, door jambs, shelving, and such internal work. Compared with the imported pinewoods it is not a first-class timber, but if it can be procured in a seasoned condition it is good and serviceable for internal work. It grows in abundance in Queensland and northern New South Wales.

342 (2) Cypress Pine.—Under this name are included a number of pine timbers, the most valuable of which are:—

(a) *Callitrus calcarata.*	(c) *Callitrus arronosa.*
(b) „ *glauca.*	(d) Queensland Kauri.

C. calcarata, called "cypress pine," "black pine," "red pine," and "Murray pine," is of a rich brown colour, with beautiful figuring. It is found from northern Victoria to central Queensland.

C. glauca, called "cypress pine," "white pine," "common pine," varies in colour from a very light to a dark brown. It grows in all the States on the mainland.

C. arronosa, called "cypress pine" and white pine," is a fairly dark, brown-coloured timber, with a silky grain, which grows in the coast districts of Queensland and the N.E. of New South Wales.

343. The Cypress pines are valuable building timbers, being durable under reasonable conditions, easily worked up to a smooth surface and very beautiful in appearance. The knots, which are very plentiful, are in no wise defects, for they do not become loose. Serious drawbacks of the cypress pine are brittleness and inflammability, but against these disadvantages may be put the quality of being nearly impervious to the attacks of white ants. Cypress pine is used for all kinds of work, particularly flooring.

344. (3) Huon Pine. *Dacrydium franklini.*—An exceedingly durable and tough timber, of light weight, and pale yellow colour. It was much prized for joinery work, but owing to an extensive use of it in the past, it is scarce, and can, as a consequence, be seldom used except for cabinet work, for which it is well fitted. In first-class joinery work it is used for panels. It is a Tasmanian timber.

345. (4) Brown Pine. *Podocarpus elata.*—This timber is known also as "white pine," "she pine," "pencil cedar," "native deal," and "plum pine." It is free from knots, fine-grained, easily worked, and some of it is very beautiful in appearance. Its chief quality is its resistance to white ants and the *teredo,* and on this account it is used for piles. (See Art. 30, *ante.*). It is also largely used for all kinds of joinery work. Grows in New South Wales and Queensland.

346. Queensland Kauri. *Agathis robusta.*—A pine like New Zealand kauri, but much inferior.

IMPORTED PINEWOODS

347. The following are the principal pine timbers which are imported and stocked by timber merchants:—

(1) Oregon Pine.	(5) Clear Pine
(2) Redwood ,,	(6) Pitch ,,
(3) Baltic ,,	(7) American Spruce.
(4) Kauri ,,	(8) Baltic ,,

348. (1) Oregon Pine. *Abies douglaisi.*—This is a hard, rather coarse-grained, reddish-coloured, fir timber, possessing a fair strength, and is very durable. It is very extensively used about Sydney for scaffolding, beams, posts, joists, rafters, fascias, flooring boards and even in joinery work for window frames and sashes, and door jambs, etc. It is very resinous, and, consequently, on account of the exudation of the gum resin, it is not very suitable for good joinery work. It comes to the market in all sizes from 2 in. x 1 in. to 18 in. x 18 in. and in lengths to from 10 ft. to 70 ft. Generally speaking, it is one of the most useful timbers in the market for general building purposes. As a timber for use as scaffolding it is unequalled, being light and yet strong and capable of being obtained in long lengths. Oregon comes from the north-west of America.

349. (2) Redwood. *Thuya gigantea.*—This is a very soft, pithy timber, of a yellowish-red colour. When dry it is very light, but is not strong. It is, however, very durable in exposed positions, and is, in consequence, an excellent timber for fascias, barge boards, louvres, shingles, weather boards and other such parts of buildings which are exposed to the weather. It is also much used for skirtings, architraves and mouldings and for window frames and sashes. It is an American timber, which comes in sizes ranging from 1 in. to 6 in. thick up to 40 in. wide and in lengths up to 20 ft.

350. (3) Baltic Pine. *Pinus sylvestris.*—This is a timber which grows in northern Europe. That which comes to Australia is chiefly from Norway. It is a whitish, and slightly reddish yellow-coloured timber, exceedingly pleasant to work, fairly strong and tough, and durable if not put in exposed positions. The reddish-tinted is called red deal, and the other white deal. In, or about Sydney it is used only for joinery work such as window frames and sashes and doors, but in Melbourne it is used very extensively for all kinds of joinery, skirtings, architraves, etc. In the Sydney market it is generally only obtainable in planks 11 in. x 3 in., and in deals 9 in. x 3 in. in cross section, but in Melbourne it is obtainable in a much greater variety of sizes.

351. (4) Kauri Pine. *Dammara Australis.*—This is a New Zealand timber (though a little is found in Australia) of great value. It has a fine appearance when planed up, being free from knots, very fine-grained, of a whitish-yellow colour, with a silky lustre. It is noted as being the strongest of the pine timbers, but it has a great fault, inasmuch as it shrinks and swells with change of temperature, especially endwise, unless perfectly seasoned. The grain is so close that it can be planed across the end as well as with it. It is consequently an excellent timber for turnery and carving, but is extensively and successfully used for flooring boards, door jambs, panels, staircases, etc. A special use of the timber is for making wash tubs, bakers' troughs and other such utensils, for which it is well suited, for it does not stain when wet. It can be obtained in all sizes.

352. (5) Clear Pine. *Pinus strobus.*—A white or pale straw-coloured timber, of light weight, rather soft, and durable only in dry, well-ventilated places. It is considered to be a good timber for joinery work, and is used for doors. The coarser-grained kind is known as *sugar pine,* which is extensively used for stock-made doors. Clear pine is an American timber. It comes in pieces 16 feet long by from 1 in. to 4 in. thick and up to 30 in. wide.

353. (6) Pitch Pine. *Pinus rigida.*—This is a resinous, hard, heavy, strong, durable timber, free from knots, which is imported in small quantities from North America. It is suitable for flooring boards, but is used in the very best kind of joinery work.

354. (7) American Spruce (*Abies, alba, A. nigra, A canadensis and A Rubra*) is a tough timber full of glassy knots, and liable to twist and warp. It is imported only in the form of shelving.

355. (8) Baltic Spruce. *Abies excelsa.*—An inferior white timber, full of knots, which is used very much as lining boards.

356. Strength and Weight of Timber.—The Table XXIII. has been compiled to illustrate the weight and strength of the various timbers used in building construction. Many of the timbers described in the preceding articles are omitted from the table; in some cases because authentic tests are not obtainable, and in others for the reason that the timbers are not used for other than delicate joinery or cabinet work, where weight and strength are not matters affecting their use.

357. Cutting of Timber.—Economy of course demands that a log shall be cut up to get from it as much timber as possible, but this does not mean that the log shall be simply divided into the greatest number of pieces without any regard to other matters. The use to which the timber is to be put should

be considered, and unless this is done the value of the timber is greatly interfered with. When the timber is to be used in work where the strength is a matter of importance, then the cutting-up of the log should be such as to get the strongest pieces. Again, where the timber is to be used for joinery or cabinet work where appearance is of consequence, it is necessary to cut it so that the most beautiful grain shall show; or it may be necessary, as is sometimes the case, to get surfaces which will be the most easily worked. And, these are matters affecting the user just the same as the saw-miller, for the architect or builder should see that he gets the strongest, or prettiest, or most-easily worked timber, as the case may require. This article is to deal with these matters, and to begin with it is necessary, with a view to a proper understanding, to briefly describe the structure of trees. From the centre to the bark is composed of a mass of wood fibre which is arranged in concentric layers, there being one layer for each year of growth of the tree. These layers are called "annual rings," and are generally distinct enough to be easily noticed. They are indicated on the sketch, Figure 64, by the concentric

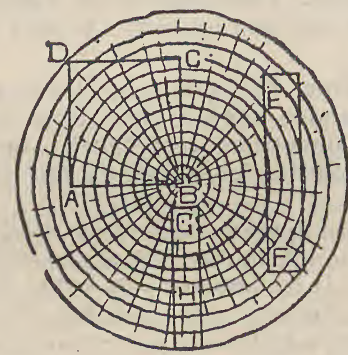


Fig. 64.

wavy, circles. Very thin, partition-like layers radiate from the centre towards the outside of the tree, passing through and dividing the annual rings into segments. These radial partitions are called medullary rays. They are illustrated by the lines radiating from the centre to the outside on the sketch, Fig. 64. In some timbers, such as English oak, they are very distinct; in others they are not so easily discerned. Timber shrinks mostly in the direction of the annual rings, consequently, if a piece of timber square in cross section with the rings in it at A, B, C, D, Fig. 64, be cut out and left to season, it will shrink most in the direction of the rings, so that the

corners A and C will be very close together, while the distance from B to D will be very little altered. Planks cut with the rings roughly in the direction of the depth, as E, F, Fig. 64, will be stronger than if cut, as at G and H, with the rings at right angles roughly to the depth. In many cases the prettiest grain is obtained by cutting, as at E and F, with the sides of the rings showing on the surface, but where the medullary rays are large and distinct, a very beautiful grain, called silver grain, is obtained by cutting them obliquely, as at G and H, Fig. 64. When cut this way the rays are exposed sideways at the surface, and give a pretty effect. In many cases the grain is more easily worked where the surface is formed by the edges of the rings, as at G and H, Fig. 64.

357a. Reconstructed Wood.—There are three main types of reconstructed wood:—

(a) Those built up of three or more plies on veneers.

(b) Those built up with a solid core and finished on the surface with veneers.

(c) Those reconstructed from compressed fibres.

In class (a) it is possible to obtain 3-ply about 3/16th in. thick, 5-ply about 5/16th in. or ⅜ in. thick, and sometimes 7-ply about 7/16th in. or ½ in. thick, in sheets ranging in size from 5 ft. x 2 ft. to 8 ft. x 4 ft. The plies are sliced from the logs and are glued together with special glue which is usually prepared from casein, and are so placed that the grain is at right angles to each other.

Plywoods are available in timbers such as Oregon, Queensland Hoop Pine, Queensland Maple, Pacific Maple, Pacific Oak, Queensland Walnut, etc., with both faces unsanded, with one side sanded or with both sides sanded. Plywoods have many uses in building construction and can be used as panels, veneers, etc.

(b) Can be obtained usually 13/16th in. thick in panels about 7 ft. x 3 ft. The panels are built up in laminations glued together or with fairly large pieces of timber the full thickness glued together and covered on both sides with veneers ranging in thickness from 1/16th in. to ⅛ in. The panels are mainly used in partitions.

(c) Usually referred to as wall boards and are available under many trade names, such as Caneite (cane fibres), Celotex (cane fibres), Tentest (wood fibres), and Masonite (timber exploded by high pressure into long tough fibres). Most are ¼ in. or ½ in. thick and are used for wall and ceiling finishes. Some of these boards have insulating properties. They can be obtained in sheets of various sizes.

TABLE XXIII
Showing Strengths of Building Timbers.

No.	Name of Timber.	Weight per cubic ft. in lbs.	Modulus of rupture in lbs. per sq. in.	Resistance to crushing in lbs. per sq. in.	Classification
1	Grey Ironbark	73	17866	10165	Ironbarks.
2	Red ,,	76	16275	9281	
3	Blackbutt	66	13728	7522	Pale Hardwoods.
4	Tallowwood	77	15257	7585	
5	Spotted Gum	62	13296	6753	
6	Grey Box	73	16209	8021	
7	Stringy Bark	71	13931	5985	
8	Box	..	22654	..	
9	White Mahogany	64	17745	..	
10	White Gum	..	10401	..	
11	Messmate	..	12857	..	
12	Giant Gum	..	12662	..	
13	Mountain Ash (Mararia)	..	14922	..	
14	,, (Delegatensis)	..	11342	..	
15	,, (Regnan)	..	9595	..	
16	Mahogany (Red)	75	14500	7514	Red Hardwoods.
17	Grey Gum	57	13092	7243	
18	Red Gum	62	6930	5016	
19	Sydney Blue Gum	69	12023	5889	
20	Woollybutt	63	12708	6981	
21	Jarrah	63	10699	6669	
22	Turpentine	69	11727	6364	
23	Red Slaty Gum	..	18820	..	
24	Blue Gum	..	12336	..	
25	Blue or Grey Gum	..	17816	..	
26	Cedar	35	7400	3600	Australian Soft and figured Timbers.
27	Rosewood	74	10594	6011	
28	Colonial Beech	63	15607	8253	
29	Blackwood	70	10264	6784	
30	Forest Oak	75	15492	8335	
31	Teak, Native	62	14415	7030	
32	Queensland Maple	43	14500	..	
33	Red Beech	..	10428	..	
34	Red Myrtle or Beech	..	10716	..	
35	Colonial Teak	..	13972	..	
36	Negro Head Beech	..	9868	..	
37	Cypress or Yel. Pine	41	8413	8330	
38	Cypress or Lachlan (Calcarale)	..	4359	..	
39	,, (Tasmanica)	..	9545	..	
40	Bunya Bunya Pine	..	5531	..	
41	Colonial ,,	54	8824	4199	
42	Celery Top ,,	..	10416	..	
43	Huon ,,	..	7985	..	
44	King William ,,	..	5616	..	
45	Brown ,,	..	8300	..	
46	Queensland Kauri ,,	27	10650	..	
47	,, Hoop ,,	..	11533	..	
48	,, Kauri ,,	..	7050	..	
49	English Oak	49	12000	10000	Imported Hardwoods.
50	American Oak	61	10000	6000	
51	Mahogany (Spanish)	53	7600	7168	
52	,, (Honduras)	35	11500	6018	
53	Ash	43	12000	9000	
54	Elm	34	6000	10300	
55	Teak	46	18000	12000	
56	Beech	43	9000	9360	
57	Walnut	43	..	..	
58	Maple	42	..	..	
59	Indian Teak	..	12596	..	
60	Hickory, American	..	18522	..	
61	Ash ,,	..	9786	..	Imported Softwoods.
62	Kauri Pine (N.Z.)	34	11000	5824	
63	Baltic ,,	30	7100	5500	
64	Redwood	23	6000	5200	
65	Oregon	32	11171	7125	
66	Pitch Pine	41	14088	6720	
67	White Baltic Pine	..	7346	..	
68	Red ,,	..	11799	..	
69	Japanese ,,	..	7455	..	
70	Pacific ,,	..	6466	..	
71	White (New Zealand)	..	5035	..	

THE TESTS.—1 to 7, 16 to 20, 26 to 31, are extracts from Professor Warren's valuable work on "The Strength and Elasticity of New South Wales Timbers"; 8 to 15, 21, 23 to 25, 32 to 48, 59 to 61, 65, 67 to 71, by the author; the others are from "Rankin's Civil Engineering," "Molesworth's Pocket Book of Engineering Formulæ," and "Rivington's Notes on Building Construction."

CHAPTER VIII

CARPENTRY AND JOINERY

358. Carpentry is distinguished from joinery as being that part of the timber work which is directly connected with the stability of the building, as for instance, the floors and roof; while the joinery consists of the doors, windows, stairs, trimmings, fittings, etc. The joints in carpentry are, however, closely related to those used in joinery, consequently it will be convenient to take together, and describe, the principal joints used in the two classes of work.

Joints

359. Lapping consists of putting the ends of the two pieces of timber, one over the other, as shown at A, Fig. 65, and

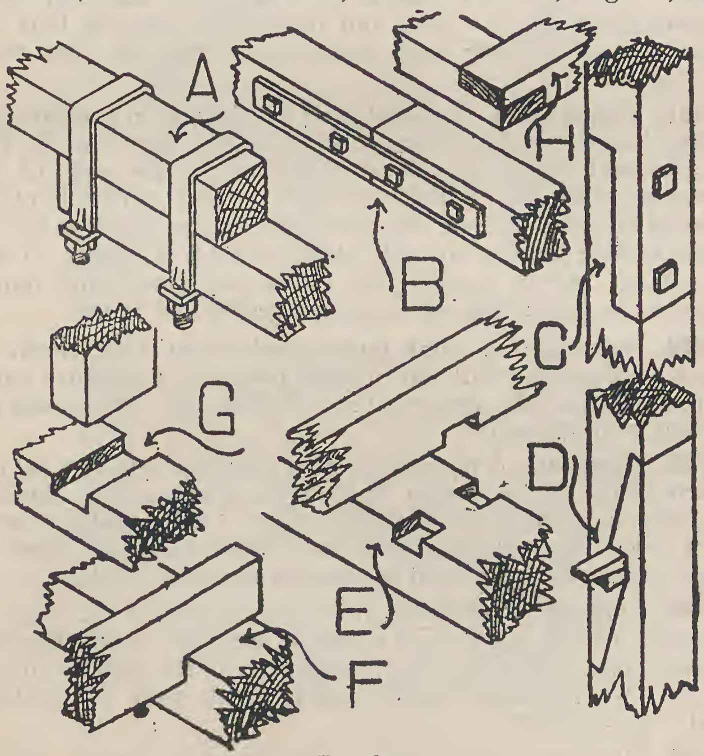


Fig. 65

securing them together with bolts only, or with bolts and straps. This joint is, however, ugly on account of the want of appearance of continuity in the pieces as joined. It is, moreover, not suitable for tensile or compressive stresses.

360. Scarfing is a better form of joint, inasmuch as it gives the appearance of continuity, and can be made to suit either compressive or tensile stresses. The joint at C, Fig. 65, shows a scarfed joint for compressive stress. In this case the two pieces are cut one into the other, so that the whole of the resistance of the fibres is available against compression, while it is not unsightly by any means. The two pieces are held together by bolts, or by bolts and straps. The example D, Fig. 65, illustrates a case of scarfed joint for tensile stress, with an arrangement of wedges in the centre for tightening up the joint. In cases where extra strength is required straps and bolts are added. At times very complicated scarfed joints are made with a view to increased strength, but, without altogether condemning these, it is well to remember that simple joints are the easiest to make with accuracy, and, consequently, are the best, and indeed it is seldom that the exigencies of building work require more than the two cases given above.

361. Fished Joint. A useful joint for timbers in compression is that known as the "fished joint." This is shown at B, Fig. 65. As will be seen, it consists of butting the ends of the pieces together, and securing them in position with side plates of steel bolted together. In cases, where clumsiness is not an objectionable feature, the side plates may be of timber. It will be noticed that a scarfed joint with side plates and bolted together is a combination of scarfed and fished joints.

362. Halving is a joint much used in building work. It consists of cutting half out of each piece for a distance equal to the width of the timber. (See H, Fig. 65.) It is used for joining wall plates, etc.

363. Notching. A notched joint is made by cutting a bit out of one piece, so that it may fit over the other, and so obtain a shoulder hold, as at F, Fig. 65. When a bit is taken out of each piece the joint is known as *"double notched."* Both of these joints are much used in flooring and roof work.

364. Cogging consists of the form shown at E, Fig. 65, which is a kind of notch. As will be seen, the notch does not extend right through, but a bit is left in the middle in one piece. This joint is suitable, and is much used, for jointing joists on to girders.

365. Housing, shown at G, Fig. 65, is a simple way of

connecting the end of one piece with the side of another. It is much used in floor and roof work, and also in joinery work to some extent.

366. Mortise and Tenon. This joint, like housing, is used for connecting one piece endwise with the side of another. There are many forms of this important joint, but the examples given will illustrate those in general practice. (See Fig. 66.) A is a tenon, B the shoulder, and C the mortise. When the joint is near the end of the piece with the mortise, the tenon is cut back a little, as shown at E, Fig. 66, the

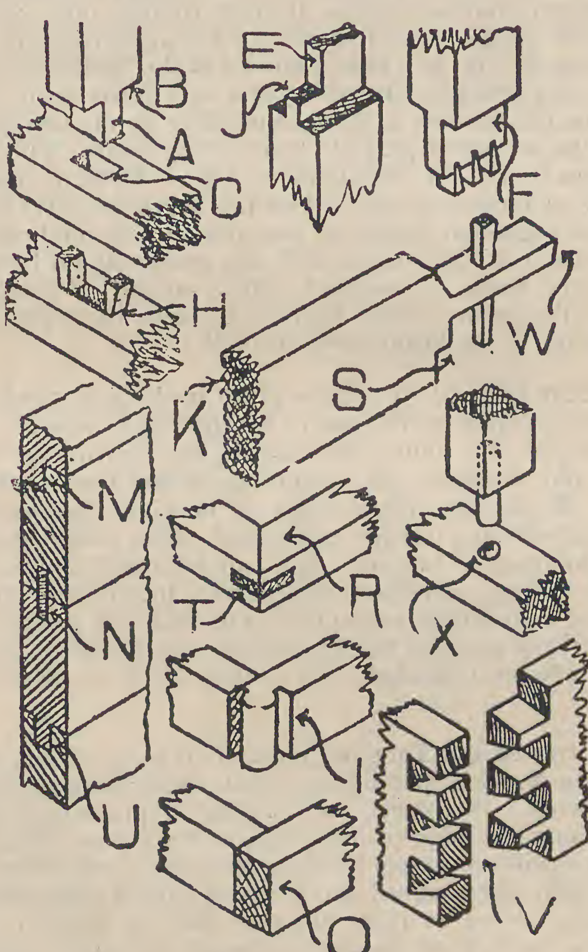


FIG. 66

shortened part of the tenon being called the "haunch." The haunch preserves the strength at the root of the tenon, and avoids cutting the mortise right up to the end of the other piece. The ordinary mortise and tenon joint is fastened by driving wedges in at each side of the tenon at the back of the mortise. (See H, Fig. 66.) Of course, this is not possible where the mortise does not go right through. In the latter case, wedges are put in at end of tenon, before the latter is inserted in the mortise. Then, as the tenon is pushed in, the wedges are driven home by being pushed against the bottom of the mortise. (See F, Fig. 66.) The wedges extend the end of the tenon, and so prevent it from coming out. Such are called "fox wedges." An important form of mortise and tenon is shown at K, Fig. 66. This is known as the "tusk tenon," and is used for jointing joists with joists, and joists with girders, to weaken the timbers as little as possible by the mortise, and yet get the strongest possible hold by the tenon. The proper proportion is to have the shoulder S $\frac{1}{6}$ of depth of joist; the depth W of tenon also to be $\frac{1}{6}$ of the depth of joist; and the bottom of the tenon should be just at centre of the beam with the mortise in it. Where possible the tenon should be carried through the beam and secured with a wedge. If this cannot be done, the tenon should be held in place by a pin, driven from the top of the beam down through it.

367. Butt Joint. This term is given to the joint made when one piece is butted on the end of another, as shown at O, Fig. 66. It is also the joint when boards are joined together by planing and shooting, and sometimes gluing the edges, as at N, Fig. 66. In the rough kinds of flooring the boards are merely placed edge to edge and nailed. This would be known as butt-jointing. The butt joint can be much improved by inserting tongue pieces or "slip feathers" in grooves run along the butted edges. (See example N, Fig. 66.) The joint is much stronger if the grain of the slip feathers is crosswise. A right-angled butt joint beaded with return bead is shown at I, Fig. 66.

368. Grooved and Tongued Joint. This form of joint is used for joining flooring and lining boards, and in many parts of joinery work. It consists of forming a projecting slip or tongue along the edge of one piece, and a groove, into which the tongue will accurately fit along the edge of the other. (See U., Fig. 66.) The tongued and grooved joint is also used often for joining pieces at right angles. (See D, Fig. 67, which illustrates method of joining a board at right angles to another.)

369. Mitre Joint. This joint is illustrated at R, Fig. 66. It consists of joining two pieces so that the line of meeting, or the joint, forms a bi-section of the angle at which the two pieces meet. The pieces are held together by nails in rough and external work, and by glue in the lighter work of joinery. Sometimes a thin slip of wood called a "key" is cut in across the angle as shown at T, so as to strengthen the joint. The mitre is used occasionally in conjunction with other joints, as, for instance, the rebate, the tongue and groove, the dovetail, etc.

370. Rebate Joint consists of rebating each of the edges to be joined so that they lap into each other, as at M, Fig. 66.

371. Dove-tailed Joint. In this kind (see V, Fig. 66) tenons or "pins" (shaped like a bird's tail extended) on one piece fit into mortises or "sockets" cut out of the other piece. The spaces between the pins should be equal to the size of the pins, so as to make the strongest joint. The *dove-tailed* joint is useful for joining at right angles the edge joists of suspended landings, verandah plates, etc., in carpentry work; but it is more particularly suited for the better class of joinery work.

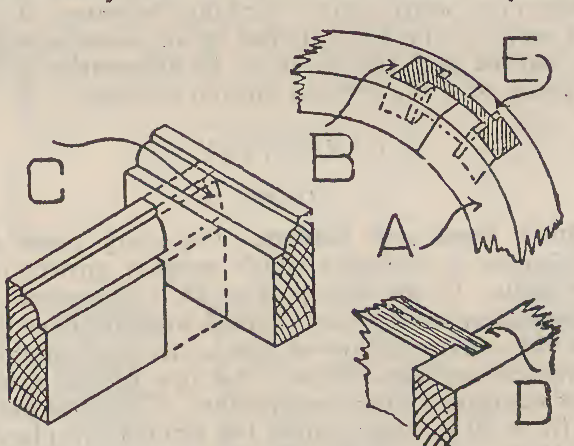


Fig. 67

372. Dowelled Joint. This joint is really a mortise and tenon joint, in principle, as will be seen by X, Fig. 66, which shows a dowel and socket for same. It consists of a pin, which is usually of some hard wood, but sometimes of metal, inserted into each piece joined together. It is used generally in connection with the butt joint.

373. End Butt and Keyed Joint is shown at A. Fig. 67. As will be seen, this consists of securing two pieces end to end

with a sort of wooden clamp or "key," as it is called, which is a narrow tongue passing from one piece to the other and having enlarged ends (B) to form a hold in each. The joint is tightened up with wedges inserted at shoulders (E) nearest to the joint. This joint is used for securing segments of curved sashes, etc.

374. End Butt Joint, with Connecting Screw. A joint to serve the same purpose as Art. 373 is often made in handrailing work. The ends are butted together, as shown at A, Fig. 67, but, instead of the key, a metal screw, with threads at both ends, is inserted, and by means of this screw the joint is tightened. The best kind of screw has nuts at both ends. These nuts are put in and tightened up, through mortises at sides, and near the ends of the pieces joined.

375. Scribed Joint is used principally for joining mouldings in internal corners where it would be difficult to get a mitre joint tight. By reference to C, Fig. 67, it will be seen that the end of one piece is cut out so as to be the exact reverse of the face of the other, and when pushed tight up against it the joint will be a perfect intersection. From the outside it has the appearance of a mitre joint. Scribing, however, in a more extended sense, is the term applied to all joints in which one piece is marked and cut so as to fit accurately up against another piece, or wall, with an uneven surface.

CARPENTRY

Floors

376. Story Posts and Girders. The story posts are the timber columns or uprights which support girders carrying floors or walls. In the sketch, Fig. 68, a story post (A) is shown supporting two girders, joined together over its head, and with the superstructure of joists, etc., and another story post to support an upper floor. This is a typical example of factory or warehouse floor construction. The posts are spaced from 16 ft. to 20 ft. apart, while the girders are placed from 10 ft. to 15 ft. apart. In Fig. 68 the girders are shown butt jointed, and to improve their bearing a cap or "bolster" piece is put extending for some distance under them, on top of the column. The girders are bolted to the bolsters, as shown at K, while the head of the post is secured to the bolster with a mortise and tenon joint. In the case of a post, resting on the ground, the foundation is made with a block of stone or concrete supported on brick in cement or concrete foundations, the foot of the post being tenoned or dowelled in the stone or concrete. Upper story posts are tenoned into the

girder on which they rest. In some cases, as, for instance, shop and office buildings, where the girders are to be cased in, the bolsters may be considered objectionable in appearance, and, consequently, omitted, the girders being allowed to rest on the top of the column.

In many cases an R.S.J. laid on the flat is substituted for the wood bolster, and the upper post is supported directly on it, the side beams butting against it and supported on and bolted to the R.S.J. The posts are dowelled to the R.S.J. Where joints occur, in such cases a scarf after the style of that at D, Fig. 65, should be made, or perhaps, better still the

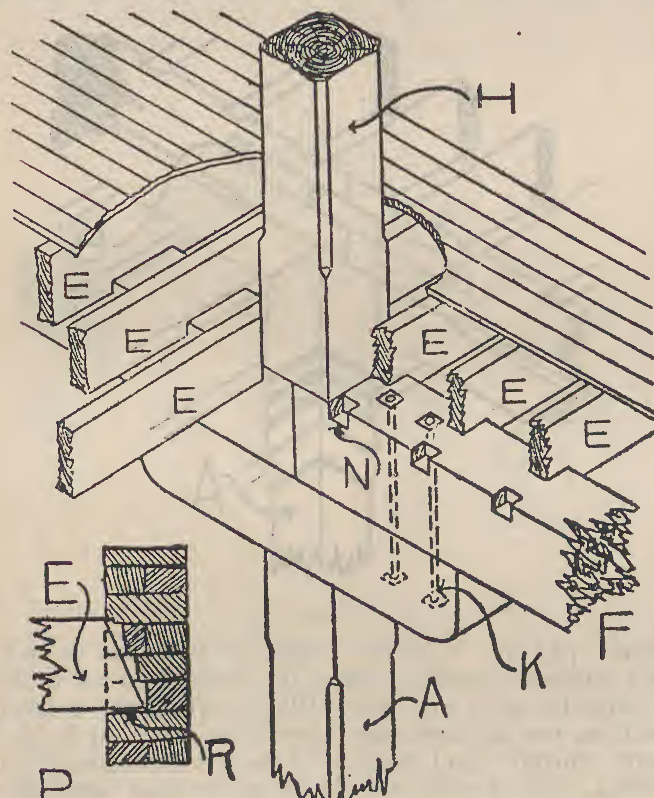


Fig. 68

butt joint improved, as at B, Fig. 69, with flush fish plates. In Fig. 69 the story post and girders are shown as dressed and cut to illustrate a method of finish in cases where appearance is a matter of importance. Care should, however, be taken not

to cut too much away from the post, as there is danger of rendering it incapable of supporting the load to be put on it. For this reason some architects insist that nothing shall be cut from the post, but that whatever moulding there is to be done shall be *planted on* and not *cut into* the post, thereby preserving all the timber for resistance to the stresses. In any case, of course, it should be provided that the least cross section of the post shall be sufficient for strength required. In the rougher, or mill construction, where strength is the main object in view, the posts and girders are not as a rule dressed, but are left as from the adze or saw, the "arrises" or sharp edges only being removed. A rough stop chamfer is

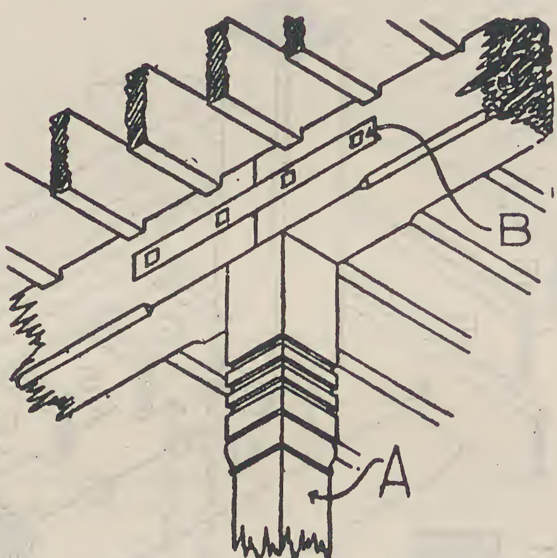


Fig. 69

sometimes put on. Whether rough construction or not, the bearing surfaces should always be dressed so as to render them perfectly even and true. When setting the story posts in position, the greatest care should be taken to have them perfectly upright, and that all bearing shoulders be quite horizontal. The girders should be quite level, and the ends in walls should bear on templates. The brickwork or masonry of the wall should not be built close up round end, sides, and top of part in the walls, so that there may be an access of air to prevent dry rot. This provision is also of value in case of fire, where the burning girders may fall out of the walls without pulling the latter down, as would be the case if they were

tightly secured. Story posts and girders, though sometimes of imported pine, are generally of Australian hardwood, the best for the purpose being ironbark. In cases where the best beams available are not sufficiently strong to carry the loads to be borne, it becomes necessary to artificially improve their strength. The simplest way to do this is to cut the beam into two equal pieces (cutting in the direction of the depth and length). The flitches are then reversed (that is to say, the outer sides are placed so as to be inwards), and a steel plate about ½ in. thick (or as the case may require), and of the length and depth of the beam, is put between them and the whole bolted together. Instead of the plate, steel trusses composed of struts, tension piece, keybolt and abutment connections are sometimes bolted in. In other cases metal tie rods are used.

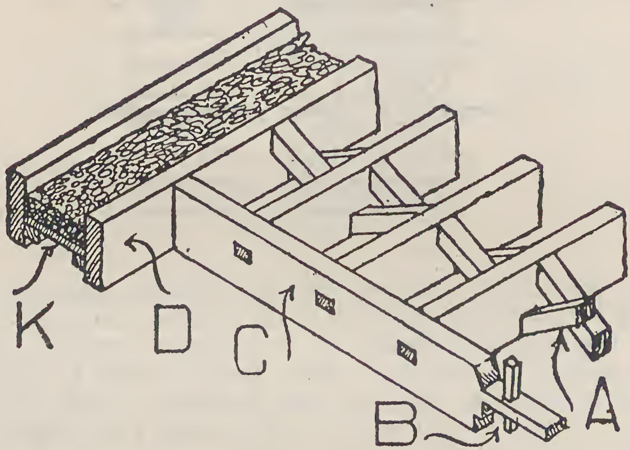


FIG. 70

377. Joists are the pieces of timber on to which the flooring boards are nailed, and which support the ceiling material.

378. Joists for Floors, near the ground, are supported at the ends near the walls by plates of hardwood, generally 4 in. x 3 in. in cross section, which are set on to 9 in. x 4½ in. brickwork piers, which project from and are bonded to the foundation walls and spaced not more than 36 in. apart. One of these piers is shown at B, Fig. 48, *ante,* and at P, Fig. 71. Sometimes a projection 4½ in. out from foundation wall is carried right along, and so gives a solid bearing throughout for the plate. An example of the latter is given at A, Fig. 48, *ante.* It will be seen that by having these piers, or the plate wall, the building of either plates or ends of joists in the wall

is avoided, and this is an important matter, for timber should not, if possible, be built in brick or masonry walling. Hardwood bearers of about 5 in. x 2 in. arranged under joists, parallel with plates, should be set at intervals apart of not more than six feet. (See B, Fig. 71.) These bearers should be supported by brickwork piers, about 9 in. or 14 in. square in cross section, and spaced not more than 5 ft. apart. When bearers, as above, are set under the joists the spans would not be more than 6 ft., consequently the joists need not be more

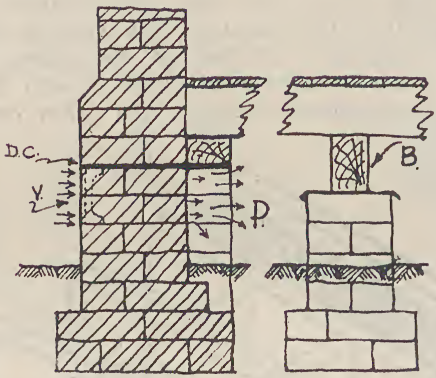


FIG. 71

than 5 in. x $2\frac{1}{2}$ in. in cross section. In most cases the joists are slightly notched, as required, on to plates and spiked. The joists are generally spaced 18 in. centre to centre, and, for finish round hearths, etc., plate walls should be built for reception of plates for necessary bearing of ends of joists. Plenty of space should be left under lowest part (bearers and plates) of ground floors, and through currents of air should be provided for by plenty of ventilators, an example of which is shown at V, Fig. 71. Australian hardwood (such as tallow wood) is the best to use for plates, bearers and joists of ground floors; and as a preservative against vermin, such as white ant, the whole lot should be well soaked with kerosene (waste) tar. The bearer piers should be capped with galvanised iron as a preventative against white ants.

378a. Timber Floors on Concrete. It often happens in framed buildings that a timber floor finish is required where the floors are composed of concrete. In such cases dovetailed joists about 3 in. x 2 in. in section spaced 18 in centre to centre are let into the concrete when it is poured, and the top surfaces are allowed to stand $\frac{1}{2}$ in. above the concrete. A layer of bitumen is spread over the concrete, finishing flush with the

tops of the joists. The flooring boards are then nailed to the joists.

379. Joists for Floors of Upper Stories. The joists of floors for upper stories, and for ground floors with basements, are generally arranged with as long a span as possible to avoid the inconvenience of upright supports. In ordinary dwellings, the walls of the rooms are not, as a rule, too far apart to allow of the joists spanning the distance; but in large rooms, and in factories, warehouses, hotels, public buildings, etc., the rooms are often very large, and it is impossible to have joists in one span over them, and girders (often with columns) are necessary.

380. To describe these different cases it will be best to divide them as follows:—

(a) *Joisting of ordinary floors over spaces of small area requiring only short spans.*

(b) *Joisting of floors supported at intervals over spaces of large area which it would be impossible to span with single joists.*

The latter class may be subdivided as follows:—

(1) *Joisting supported by girders.*

(2) *Joisting of double floors.*

(3) *Joisting, etc., of framed floors.*

381. (a) Joists of Ordinary Floors. In common work (where the span does not exceed 18 feet) the joists are put in single pieces extending from wall to wall. When a ceiling is necessary they also serve to carry it, the battens being nailed to their bottom edges. A sketch of part of an ordinary floor is shown in Fig. 70.

382. (b) Joists Supported by Girders. In this kind the floor is really a case of an ordinary floor, as far as the joists go, but the span would be too great for the joists themselves, and the support of girders would be necessary.

An example of joisting supported by girders is shown by Fig. 68. The joists would be *double-notched* or *cogged* on to the girders. The spaces between the girders are called *bays*, and when ordering the joists it is well, for the purpose of tying the lot together, to have some of the joists in lengths long enough to reach over a couple of bays. Like case (a), the joists would be required to carry the ceilings.

383. (b2) Joists of Double Floors. The joisting in this kind is supported at intervals of not more than 6 ft. by small girders called "binders"; but the ceiling would not be carried by the

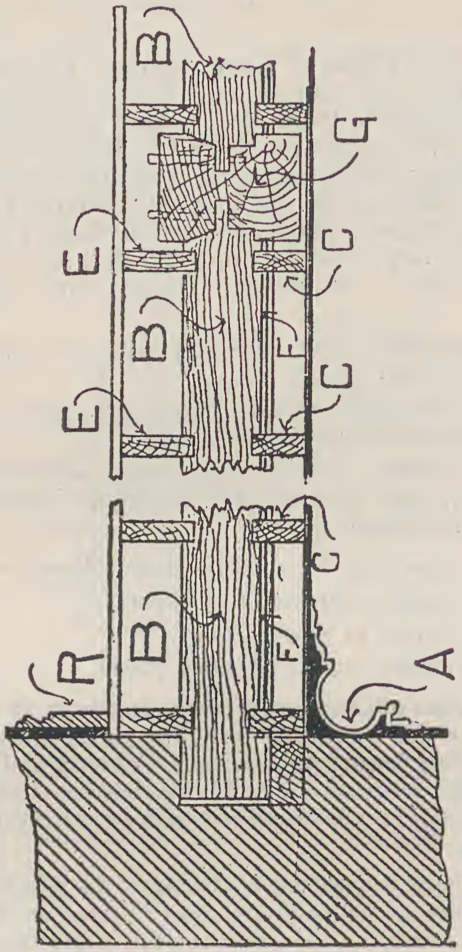


FIG. 72

floor joists—a separate set of under-joists (called ceiling joists, and secured by cutting on to fillets or by nailing to bottoms of girders) being provided to carry the ceiling. By this means the vibration of the floor is not so easily communicated to the ceiling, and the chances of it being cracked and loosened are reduced. It will be noticed that the binders are not introduced so much for support to joists as for separating the latter from those to carry the ceiling.

384. (b3) Joisting, etc., of Framed Floors. This class is really an elaborate kind of double floor, the principle (viz.,

separate joists for floor and ceiling) being the same; but for a big span the binders would not be sufficient support, and girders are introduced to carry the binders, which in their turn carry the floor and ceiling joists, as described in preceding article. In Fig. 72 is shown the section of part of a framed floor. E E are the floor joists cogged or double-notched to the binder (B); C C are the ceiling joists cut on to fillet (F) at side of binder (B). The binder (B) is shown, by a side view, tusk tenoned into the girder, an end section of which is shown at G.

385. Double and Framed Floors are hardly to be recommended, as they have a lot of timber in them, and they lose all stiffness if there is the least shrinkage of the timber of girders or binders. In these days so much iron and steel are used in floor and ceiling work, with such good results—especially if proper fire-proofing provision is made—that heavy framed timber floors are out-classed altogether. The same cannot be said of the single floor supported on hardwood girders and story posts. The construction is simple, giving strength and stiffness.

386. The following articles, 387 to 391, deal with matters relating to upper floor joisting generally, irrespective of the kind of floor:—

387. Spacing Apart of Joists. Joists are usually spaced 18 in. from centre to centre. Joists are, however, sometimes 12 in. and 15 in. centre to centre.

388. Bearing of Joists in Walls. The end bearings of joists in walls should not be less than 4½ ins., and they should be notched on to wrought iron plates (see R, Fig. 68) about 2 in. x ⅜ in. in cross section. It is best to have the ends of the joists cut on the bevel, as shown at P, Fig. 68. If cut this way, less of the brickwork is interfered with, and in the event of fire the burning joists may fall out without damaging the walls, as they would, by leverage, if square ended.

389. Trimming. Where openings, such as hatchways and stair well holes, are to be formed in the floors, the ends of the joists cut through are "tusk" tenoned into a supporting cross piece called a "trimmer," an example of which is shown at C, Fig. 70. The trimmer should also be tusk tenoned (as B, Fig. 70) into each of the two long joists called *trimmer joists* (one is shown at D in Fig. 70) at the sides. Since the trimmer and trimmer joists have to carry the weight of the load on the trimmed, as well as on themselves, they should be stronger than the common joists. As a rule, they are made from ¼ in.

to ½ in. thicker, as the size of the opening may render necessary. Floor and ceiling joists should be trimmed round all fireplaces and flues. (See Art. 173, *ante*, in regard to flues.)

390. Strutting. To increase the stiffness of the floor the joists should be "strutted," or, as it is sometimes called, "bridged." This is done either by *"herringbone"* or *solid strutting*. The former consists of 2 in. x 2 in. pine or hardwood cut in between joists in lattice fashion, as shown at A, Fig. 70. The solid strutting is composed of pieces of board about 1⅛ in. thick and about the same depth as the joists. These pieces of board are cut in vertically between the joists and kept in rows. Great care should be taken that all the strutting, whether herringbone or solid, is well nailed to the joists. Each lot, or bay, or joisting should have rows of strutting spaced not more than 5 ft. apart.

391. Pugging. With a view to preventing the passage of sound from one story to another, through the floors, boarding about 1 in. thick is put in horizontally, resting on side fillets (see K, Fig. 70) between the joists. On the top of the boarding is put the "pugging." This may be composed of either (1) coarsehair mortar; (2) lime mortar and smith's ashes; (3) lime mortar and chopped straw; (4) shavings which have been well steeped in hot lime; (5) special patent pugging.

NOTE.—There are various patent acoustic materials such as Caneite, which have sound-proofing properties, and are fixed to joists as ceilings instead of the pugging described above. (See paragraphs describing ceilings.)

392. Weight to be Carried on Floors. The Table XXIV gives the weight, per square foot of area, carried by floors in different kinds of buildings. In special cases, such as factories, where there is heavy machinery, or in warehouses, where the stock is of a particularly heavy character, the weight per square foot should be ascertained by experiment.

TABLE XXIV

The following table of maximum loads for floors of different kinds of buildings prepared by the Municipal Council of Sydney will be found of practical value:

Private dwellings	50 lbs. per sq. ft.
Public buildings such as churches, schools and theatres	100 ,, ,,
Office buildings	60 ,, ,,
Warehouses, factories and stores Minimum	150 ,, ,,

The latter to be increased as needed to suit the special load to be carried.

393. Sizes of Common Joists. So that safety may be arrived at with economy, it is best, especially in cases where large quantities of timber are involved, to calculate the sizes of the joists to suit the conditions of load to be borne by the floor under process of design. Joists should be calculated as bearers with a distributed load. Particulars as to how to do this will be given later on. It is, however, hardly necessary to go to the trouble of determining the sizes in cases or ordinary floors, because experience provides plenty of information in this respect, and it is best to follow the general practice. Table XXV. gives usual size of common joists of pine. The different kinds of Australian hardwoods (see Arts. 278 to 304) are stronger than pine and well suited for joists, and, if used, the size may be a little smaller than those given in the table, but care must be taken that the hardwood is dry, for, unless quite seasoned, it would be unwise to reduce the size. The oregon pine, to which the table may be applied, is much used, and is a very suitable timber for joisting.

TABLE XXV

Showing suitable sizes of pine common joists for ordinary floors. Joists to be spaced 18 inches centre to centre.

Breadths in inches.	1½	2	2½	3	4
Length of Span in feet.	Depth in in.	Depth in in.	Depth in in.	Depth in in.	Depth in in.
6	7	6	—	—	—
8	8	7	—	—	—
10	9½	8	7½	—	—
12	10½	9	8½	—	—
14	11½	10	9½	—	—
16	12½	11	10½	10	—
18	—	12	11½	11	—
20	—	13	12½	12	11
22	—	—	13½	13	12

NOTE.—The depths given in the table are in most cases not the exact result of the calculations, the intermediate fractions being raised, for the sake of convenience in practice, to the ½ or full inch as the case required.

394. Flooring Boards. These are the pieces of timber, laid all over and secured to the joists to form the upper surface of the floor. The boards are by no means an unimportant part of the whole floor, and to have them of suitable quality, thoroughly seasoned and well laid is of great importance; in the first place, because unless strong and durable they will be quickly worn out; and, in the next, if not well seasoned and skilfully laid, they will shrink and split, and the interstices so caused will be receptacles of dust and filth, causing danger to health.

395. Timber for Flooring Boards. Tallow wood, jarrah, cypress pine and colonial beech are the best of the Australian timbers for flooring boards. Colonial pine will also do well, but should not be used in preference to the timbers mentioned above. Of the imported timbers, kauri, oregon, baltic and pitch pine do well for flooring. As before remarked, it is of the utmost importance to have the timber for flooring well seasoned, and with a view to having it dry it should be brought, if possible, on to the site and stacked as soon as the building is commenced.

396. Sizes of Floor Boards. Flooring boards should be as narrow as possible, so as to reduce the tendency to shrink; 4 in. is a good width, but they should under no circumstances be wider than 6 in. The thickness ranges from $\frac{7}{8}$ in. to $1\frac{1}{2}$ in., the thickness most generally used for ordinary work being 1 in.

397. Joints of Flooring Boards. These may be divided into two kinds, viz.—

(a) Longitudinal joints.
(b) Cross ,,

398. The Longitudinal joints are those made by the boards sideways with each other. The cross joints (or "heading" joints, as they are called) are those made by joining piece to piece endwise in the length. The longitudinal joints are made either as:—

Plain Butt Joint.
Or *Ploughed and Tongued Joint.* See C, Fig. 73.
,, *Rebate* ,, See A, Fig. 73.
,, *Tongued and Grooved* ,, See B, Fig. 73.
,, *Secret Nail Joint,* as at A, B & C, Fig. 73.

The tongued and grooved joint (B, Fig. 73) is the one most used in practice for ordinary work. Care should be taken that the groove is not too near the upper surface, for, if it is, the board will very soon be worn down to the groove and rendered useless. The shoulders of the tongued and grooved edges should be quite square with the faces of the boards, and the tongues should be a little less than the depth of the grooves, so that the boards may be brought tight up against each other with the cramps, which latter are screws temporarily attached to the joists, and used for pushing the floor boards tight together before being secured. In ordinary work the boards are secured to the joists by nailing with two nails, into each joist, along the length of each board. The nails should be punched in and, unless in very common work, the holes well

stopped with putty. In first-class work the nail holes, even if stopped with putty, are objectionable in appearance, and the secret nail joint (shown at A, Fig. 73) is used. In this case one board is laid at a time, and nailed at outer edge, the other edge being caught in the groove of last-laid board. As will be seen, the nails would be hidden from sight. The tongued and grooved joint may, however, be laid with hidden nails, as shown at B, Fig. 73.

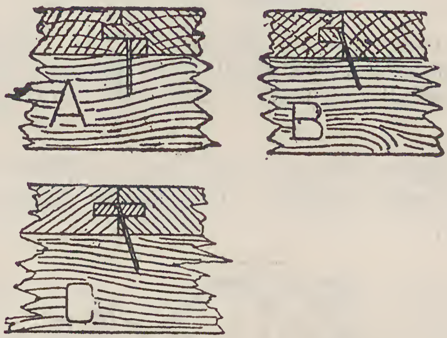


Fig. 73

399. The heading joints should break with each other, and are made either by:—

Plain Butt Joint,
Or Bevelled „ „
„ Ploughed and Tongued Joint.

All joints, of course, should be on joists. Care must be taken to have the boards so joined, exactly of the same width, otherwise an ugly break and crevice will occur. This trouble is very likely to arise if the boards are mixtures of different "millings." For secret nailing the joint used would be the ploughed and tongued.

400. Parquet Flooring consists of small pieces of fancy timber of different kinds inlaid as bordering into a first-class floor of boards; or set close together in geometrical design all over and supported by a strong foundation of ordinary flooring boards. The upper surface is generally polished, and when well executed this kind of floor is not only very ornamental in appearance, but very nearly approaches the ideal from a sanitary point of view, for there are no cracks or crevices, and consequently no harbour for dust.

Many of the Australian fancy-figured timbers are eminently suited for this work. Parquet flooring may be obtained, made in squares all ready for laying.

TIMBER ROOFS.

401. Forms of Roofs. The ordinary forms of roofs classified as regards outward appearance are as follows:—

(a) Lean-to roof.
(b) Gable ,,
(c) Hipped ,,
(d) Flat ,,

There are other special forms, such as mansard, curved roofs of all kinds, and domes, but more than a very brief reference to these, at a later stage, is impossible within the limits of this book.

402. The sketch (Fig. 74) has been prepared to illustrate the ordinary forms of roofs. It is merely diagrammatic, and is not to scale.

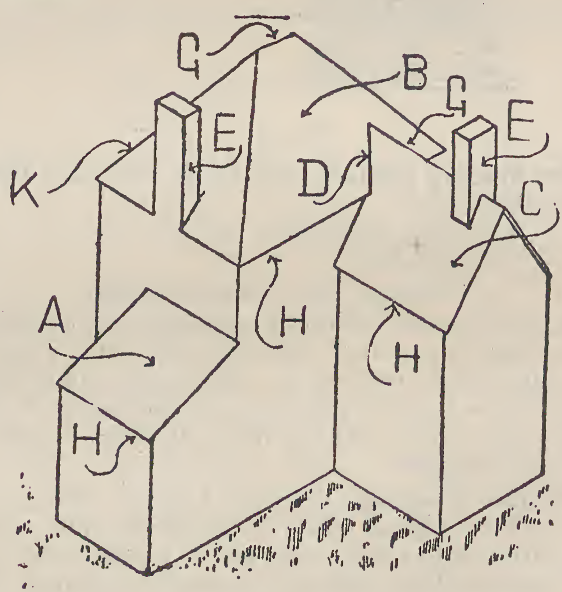


Fig. 74

403. (a) Lean-to Roof. This kind (sometimes called a skillion roof), shown at A, Fig. 74, is a simple form of roof suitable for small spans. As will be seen, it consists of one surface sloping down from back to front. What is called a *V Roof* is formed of two lean-to roofs sloping down from the side walls to a gutter along the centre of the building. The details

of a lean-to roof are shown by Fig. 75. Although sometimes the form of the lean-to is used for trussed roofs of a large span (in which case the construction is complicated), this style of roof is generally used only in rear buildings, or verandahs where no ceilings are required. If a ceiling is needed the joists may be put in as shown by dotted lines, marked S in Fig. 75.

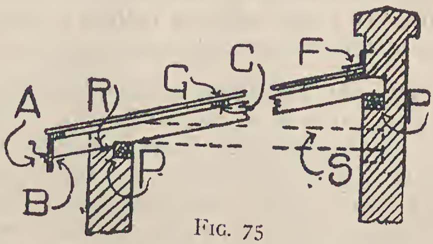


Fig. 75

404. Gable Roof. The form of the gable roof is shown at C, Fig. 74. It is a very common form, being used, perhaps, more than any other. The triangular portion of the wall is called the gable.

405. Hipped Roof. This form is shown at B, Fig. 74. It may be described as pyramidal in shape, having surfaces sloping upwards from all the eaves, the salient intersections of the surfaces being called *hips*.

406. The forms of the two latter, viz., gabled and hipped roofs, are produced by different methods of construction. The term *gable* or *hipped* is often replaced by that of the particular kind of construction. For instance, a gable roof may be built on the principle of the collar beam, and may be called a collar beam roof, and so on.

407. The Different Methods of construction are as follows:—

(1) Couple or single span.
(2) Collar beam.
(3) Couple close or tie beam.
(4) Truss.

408. (1) Couple or Single Span construction is shown at W, Fig. 76. In this case the sloping surfaces are held in position altogether by the walls, there being no cross tie in the roof itself. It is a weak form, for, there is an ever-acting, thrusting force against the walls, tending to turn them over.

409. (2) Collar Beam Construction. In this case, as will be seen by Z, Fig. 76, a horizontal tie piece, called a *collar beam*, is put in at some distance above the level of the top of the walls. This beam, known also as a collar tie, helps to keep the two surfaces from spreading, and so, in a measure, relieves the walls. There is, however, a tendency to bend outwards of the

parts of the rafters below the collar beam, and if this bending takes place the walls get an ugly thrust. To minimise the danger of bending, the collar beam should be as low as possible. In cases where a ceiling is attached to the collar beams the latter are generally called ceiling joists.

410. (3) Tie Beam or Couple Close Construction. This kind of construction, shown at Y, Fig. 76, is most generally adopted for roofs where the span is not great enough to render truss construction necessary. As will be seen by the drawing, the tie beams (really the ceiling joists) are put across at the level of the top of the walls, and are secured to the feet of the rafters. Different methods of securing the ceiling joists to the feet of the rafters are shown in detail in Fig. 76.

411. (4) Truss Construction. The kind of construction noticed in the last article does well for roofs of span up to

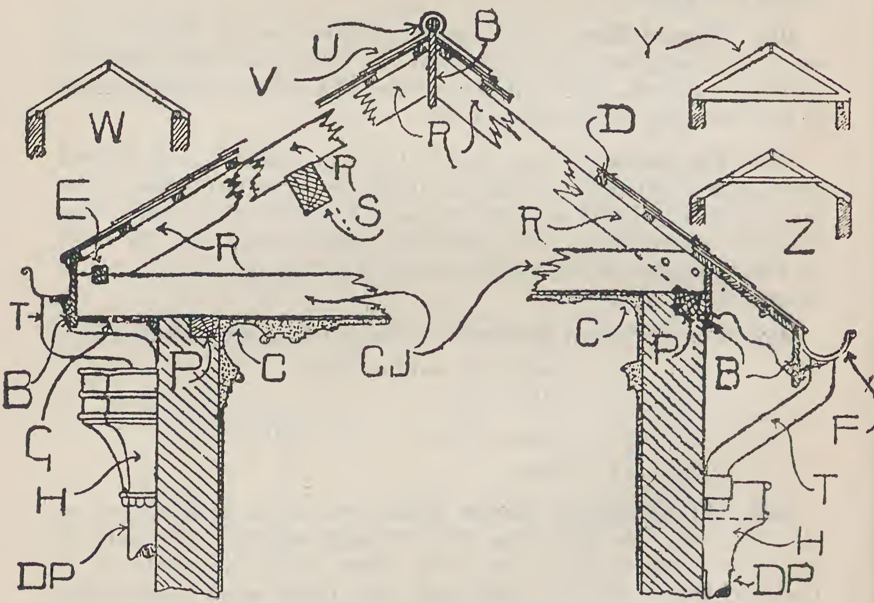


Fig. 76

about 16 ft. or 18 ft., but, when over 18 ft., it is altogether unsuitable, as the system is deficient in stiffness and it becomes necessary to substitute what is called truss construction, which consists of supporting the rafters on braced frames, spaced about 10 ft. apart. These braced frames, which also serve to

carry the ceilings, are called "trusses" or "principals." Two kinds of trusses are shown by Fig. 77. The top one is known as a *king post truss,* and is suitable for spans up to 30 ft.

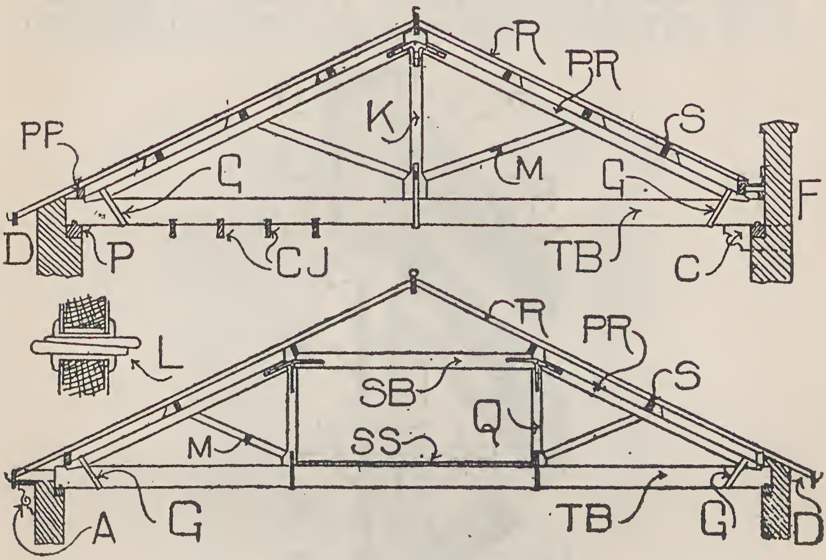


Fig. 77

412. The King Post Frame consists of:—

Tie Beam	marked	TB	Fig. 76.
Principal Rafters	,,	PR	,,
King Post	,,	K	,,
Struts	,,	M	,,

413. Pieces of Timber, called *Purlins,* stretch from frame to frame, and on these the common rafters are secured. One purlin is marked S in Fig. 77. The functions of the parts of the frame are as follows: The tie beam acts as a tie and prevents the principal rafters from spreading outwards at the feet. The king post acts as a suspender to hold the centre of the tie beam up, and so prevents "sagging" of the latter; while the struts serve to support the centres of the principal rafters. The combination of parts is therefore such, that all are acting together to resist change of form in the whole frame, and the result is a structure of considerable stiffness. A great deal, however, depends on the excellence of the methods of joining the parts together, and these will now be dealt with.

414. Joints and Details of a King-Post Truss. Enlarged views, or parts of a king-post truss, together with other portions of a roof, are given in Figs. 78 and 79. The method of shouldering and tenoning the foot of a principal rafter into the tie beam is shown in Fig. 79. To prevent the upper part of the end of the tie beam being shorn off, the distance from

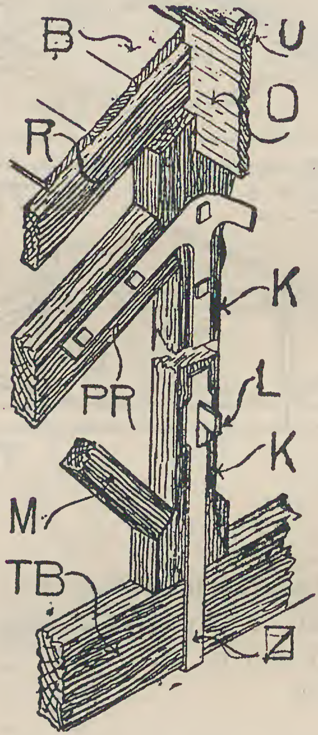


Fig. 78

the toe of the PR to the end of the tie beam should be as long as possible; a good position is to have the toe just over the inside face of the wall, as shown by the sketches. An extra guard against the toe of the PR spreading is provided in the shape of the heel strap, marked G in the sketches, 77 and 79. This is composed of wrought iron, made with cover piece and screwed ends and nuts for fastening.

415. The Heel Straps should be fixed at such an angle, that, in the event of being required to take up the stress by failure of the joint, they will be able to do so at once without allowing *any* spreading to take place.

416. The King Post, which supports (as before pointed out) the tie beam from the heads of the principal rafters, and also supports the centres of the latter per the struts, is shaped out of a single piece of timber, with base and head as shown in the sketches. The joint of the king post with the tie beam is made with a stub tenon, and the two are kept together (for it is to be remembered that the king post is pulling from the tie

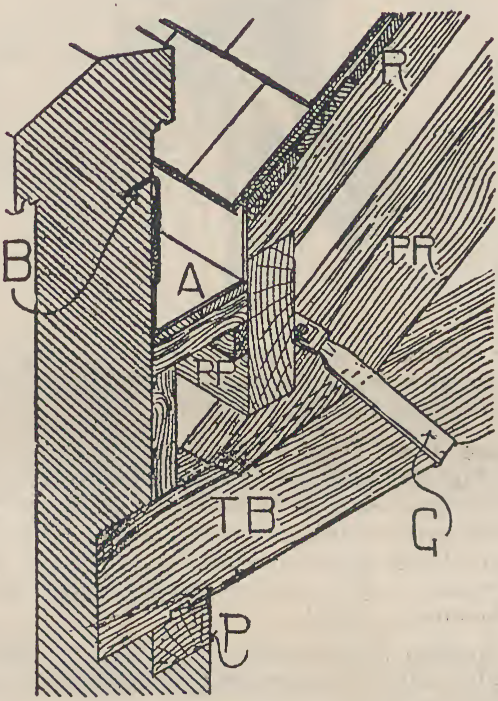


Fig. 79

beam) by the tension or *stirrup strap* marked Z on Fig. 78. When the truss is completed the tie beam should have a "camber," i.e., a slight upward curve. To bring this about the king post is cut a little short, and the tie beam is forced up to it by means of the pieces of iron called *gib* and *cotter* (marked L on Figs. 77 and 78), which act wedge fashion (using the king post as abutment), bringing up the strap and tie beam. The upper ends of the principal rafters are square-shouldered on to, and stub-tenoned into, the head of the king post, and iron straps shaped as shown on sketches, placed on both sides and bolted through, serve to hold the whole together.

417. The Struts which are in compression are shouldered on to, and stub-tenoned into, the principal rafters and the enlarged base of the king post.

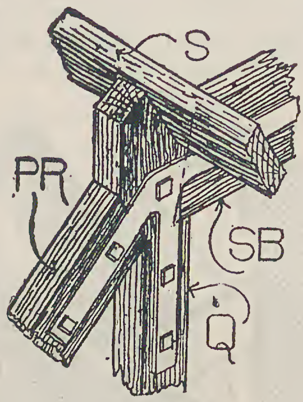


Fig. 80

418. The various other parts, such as ridges, common rafters, etc., shown in the sketches of the trusses, will be dealt with under separate headings later on.

419. Queen Post Truss. The lower of the two frames (shown by Fig. 77) is known as the queen-post truss, which is suitable for spans over 30 ft. and up to 45 ft. It differs from the king-post truss, inasmuch as it has *two* posts supporting the tie beam. These posts are called queen posts. In addition to the difference in the number of posts, there are also two additional members, called:—

(1) *A Straining Beam,* marked SB, Fig. 77, which stretches between heads; and (2) *a straining sill* marked SS, on Fig. 77, between feet of posts.

420. An Enlarged View of the head of the queen post is given in Fig. 80, in which the joints, with it, of the principal rafter (PR), the training beam (SB), and the straps are also shown. The other joints are the same as those of the king-post frame described in the last article.

421. Other Forms of Timber Truss. When the span exceeds 45 ft. two additional posts, called *princess posts,* are put, one between each queen post and wall. This form is suitable up to 60 ft. of span. Sometimes for spans about 50 ft. the king post is retained in addition to queen posts.

422. For large spans the arrangement of the various timbers

become a very complicated matter, to go into which would be impossible unless plenty of space were available, and indeed, it is hardly necessary, for the use of steel is becoming

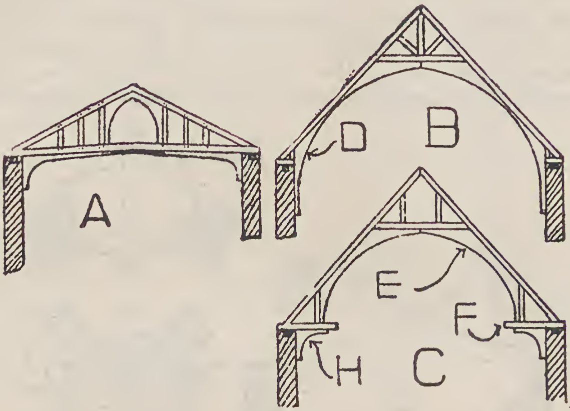


FIG. 81

general for roofs of truss construction, where it is only a matter of getting a covering for the building, as for factories or where the roof construction is hidden by ceilings, as in the case of large dwelling houses and public buildings. It is, however, impossible to avoid noticing the kinds of truss used in Gothic work, for in this style of architecture the interior of the roof is left exposed to the eye, and the construction is planned to be ornamental as well as stable.

423. Some Examples of Gothic Trusses. The sketches A, B, and C, Fig. 81, illustrate, in skeleton form, three different kinds of braced frames in use in Gothic open timbered roofs, and, though by no means covering the whole of the kinds, they may be taken as representative of the style of construction. The example A is a cambered and braced tie-beam truss, with posts spaced at intervals on each side of the centre, the spaces between the posts being filled in with cut panels. The tie beam would be cut with the upward bend or "camber" out of a solid piece of timber. The sketch B, Fig. 81, shows a collar-braced truss. In this case the collar beam is very high, and the stiffening of the truss is accomplished by the collar braces (marked D), which extend from under the collar beam and go down each principal rafter and down the walls for some distance. What is called a "hammer-beam" truss is shown by C, Fig. 81. This kind, like the last described, has a collar beam high up near the ridge and collar braces (marked E), but the latter,

instead of going down the walls, are stopped on to short projecting beams called *hammer beams* (marked F), which in their turn are supported by wall braces (marked H) going from under them and down the wall. The collar braces are also secured at their lower portions against struts which extend vertically from the hammer beams to the principal rafters. The jointing together of the various parts of these trusses is done in much the same manner, as described for the king-post

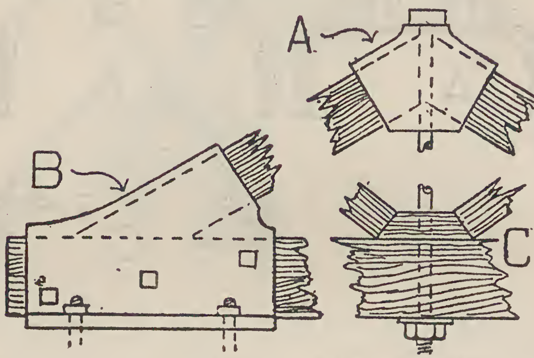


Fig. 82

truss in Art. 411 to 417, *ante*. It is, however, to be pointed out that these trusses (A, B and C, Fig. 81) are weak and entirely unsuitable for large spans, and even in small spans the walls must be thick and well buttressed to resist the thrust.

424. Trusses of Iron and Timber Combined. Fig. 82 shows examples of the use of iron in conjunction with timber in what is called a king-bolt truss. A is a cast-iron head or cap piece, shaped to receive the upper end of the principal rafters, and drilled to take the head of a wrought-iron or steel king bolt. B shows a cast-iron shoe fitted on and bolted to the end of a tie beam, and formed to also receive the lower end of a principal rafter, the lower part of the casting being shaped as a seat for resting on, and bolting to template in the wall. In both cap and shoe pieces the thickness of metal should be enough to prevent rupture. C shows the lower end of the king bolt passing through the tie beam, and also the ends of the struts stopped on to an abutment block through which the king bolt also passes and keeps in position.

425. It will be seen that the necessity of depending on shoulder and tenon joints for the stability of the frame is removed by the employment of metal for the connections, as

illustrated, and the king bolt is a great improvement on the timber king post. The use of iron and steel in connection with timber on the principal, as sketched out above, may be extended with advantage to roofs for very large spans, a good style of construction of being king, queen, and princess bolts, with timber principal rafters, tie beams, and struts.

426. Spacing Apart of Trusses and Sizes of Timbers. Trusses are usually spaced about 10 ft. to 12 ft. apart, being secured at the bearings on the wall to wall plates, as shown at P, Fig. 79, or on to stone corbels, as marked at C, Fig. 77.

427. When setting the trusses in position the greatest care should be taken to have them perfectly upright. The cross sections of timbers of trusses suitable for different spans, from 20 ft. to 60 ft., are given in the Table XXVI. As noted on the table, the sizes are by Tredgold, whose calculations, it is generally admitted, were on the safe side. Trusses made with

TABLE XXVI.*

Showing Cross Sections of Timbers of Trusses for Various Spans.
Pitch of Roofs 27°. Trusses Spaced 10 feet apart.

	Span, in feet.	Tie Beam. in. x in.	King Post. in. x in.	Queen Posts. in. x in.	Princess Posts. in. x in.	Principal Rafters. in. x in.	Straining Beam. in. x in.	Struts. in. x in.
KING POST TRUSSES.	20	9½ x 4	4 x 3	—	—	4 x 4	—	3½ x 2
	22	9½ x 5	5 x 3	—	—	5 x 3½	—	3¾ x 2½
	24	10½ x 5	5 x 3½	—	—	5 x 4	—	4 x 2
	26	11½ x 5	5 x 4	—	—	5 x 4¼	—	4¼ x 2½
	28	11½ x 6	6 x 4	—	—	6 x 3½	—	4½ x 2¾
	30	12 x 6	6 x 4½	—	—	6 x 4	—	4¾ x 3
QUEEN POST TRUSSES.	32	10 x 4½	—	4½ x 4	—	4½ x 6¾	6¾ x 4½	3¾ x 2¼
	34	10 x 5	—	5 x 3½	—	5 x 6¼	6¾ x 5	4 x 2½
	36	10½ x 5	—	5 x 4	—	5 x 6¾	7 x 5	4¼ x 2½
	38	10 x 6	—	6 x 3¾	—	6 x 6	7½ x 6	4½ x 2½
	40	11 x 6	—	6 x 4	—	6 x 6½	8 x 6	4½ x 2½
	42	11½ x 6	—	6 x 4½	—	6 x 6¾	8¼ x 6	4½ x 2¾
	44	12 x 6	—	6 x 5	—	6 x 7	8½ x 6	4½ x 3
	46	12½ x 6	—	6 x 5½	—	6 x 7¼	9 x 6	4¾ x 3
QUEEN AND PRINCESS POST TRUSSES.	48	11½ x 6	—	6 x 5¾	6 x 2¼	6 x 8	8¼ x 6	4¼ x 2¾
	50	12 x 6	—	6 x 6¼	6 x 2½	6 x 8½	8½ x 6	4½ x 2¾
	52	12 x 6	—	6 x 6¾	6 x 2¾	6 x 8¾	8¾ x 6	4¾ x 2¾
	54	12 x 7	—	7 x 6¼	7 x 2¼	7 x 7¾	9 x 6	4¾ x 2¾
	56	12 x 8	—	7 x 6¾	7 x 2½	7 x 8	9¼ x 6	5 x 2¾
	58	12 x 8½	—	7 x 7¼	7 x 2¾	7 x 8½	9½ x 7	5 x 2¾
	60	12 x 9	—	7½ x 7	7 x 3	7½ x 8	10 x 7	5 x 3

* Tredgold.

oregon or baltic pine timbers, of the cross sections, given in the table, would carry roof coverings of countess slates and pine boarding, and also ceiling joists and ceilings; for such a light covering as corrugated iron, which is put on without

boarding, the timbers may be much lighter. It may be mentioned that the tie beam, principal rafters, and posts, should, if possible, be made of the same thickness, so as to bring their faces to the same plane.

427a. Flat Roofs can either be constructed of timber or concrete, but as indicated in Table XXVII, allowance for slope must be made to take the water away. If built of timber the construction would be similar to that for an upper floor. These roofs are usually covered with layers of bituminous felt on flooring boards.

428. Pitch of Roofs. Table XXVII gives minimum pitch for different kinds of covering.

TABLE XXVII

Showing Angle of Inclination (or "Pitch") of Roof Surfaces for Various Kinds of Covering.

Kind of Covering.	Minimum Angle of Inclination in Degrees.
Copper.	3½
Lead.	—
Zinc.	4
Slates (Queens).	22
,, (other kinds).	26½
Felt (asphalted).	3½
Corrugated Gal. Iron.	11
Tiles.	from 30 to 45
Thatch.	45

429. Wall Plates are the pieces of timber laid horizontally on the walls to receive ends of rafters in lean-to (see Fig. 75), single span (see W, Fig. 76) and collar beam (see Z, Fig. 76) construction; or the ends of ceiling joists in roofs of close couple construction (see Y, Fig. 76) or the ends of trusses (see Fig. 77). Wall plates are indicated by P. in Figs. 75, 76, 79, and 83. Excepting in the case of roofs of truss construction the wall plates are, as a rule, made 4 in. x 3 in. in cross section, this size serving to take up the space of a course of bricks. It will be seen, by reference to the sketches, that in most cases the wall plate is kept on the inner edge of the wall, this position being the best. Where, however, it is desired to finish the eaves, as shown at right hand of Fig. 76, the plate may be put on the outside edge. The joint called halving (see Art. 362) is used for jointing pieces of wall plate, either when to be continuous, or at right angles. Reference to Art. 378, *ante,* will show that the term wall plate is also given to the timbers which receive ends of floor joists.

430. Ceiling Joists are the pieces of timber which are provided to carry the ceilings, and are put either—

(1) Under floor joists for lower ceilings, or

(2) Under rafters for upper ceilings.

431. Ceiling Joists Under Floors. Fig. 72 shows the relative positions of, and methods of, securing ceiling joists (CC) to *binder* (B) in double and framed floors. This system of construction is, however, the exception rather than the rule, the general method being to put the battens for the ceiling, or the "firring" for metal or such other kinds of ceiling, or lining boards, directly on to the bottom edges of the floor joists, and there is much to be said in favour of this method, for the double-framed floors are expensive and have disadvantages, as set out in Art. 385, *ante,* although it is true that with ceiling joists separate from the floor joists the effects of vibration are minimised.

432. Ceiling Joists Under Roofs. Sometimes as, for instance, in lean-to roofs for rear buildings and verandahs, the ceiling is put on to the rafters; and in collar-beam roofs the ceiling is put part on collar beams and part on rafters. In these cases ceiling joists proper are not required. But in roofs of close couple (though in this case they serve also as tie beams) the ceiling-carrying timbers are called ceiling joists. (See Art. 410, *ante.*) In roofs of truss construction ceiling joists must be specially provided, and they are either notched on to the tie beams, or spiked or cut on to fillets at side of tie beam in the same manner as they would be fixed to binder, as shown by Fig. 72. Ceiling joists cut on to side of tie beam are shown marked CJ in Fig. 77.

433. Trimming of Ceiling Joists. Ceiling joists should be trimmed for manholes, skylight openings and around flues. Also, in case of hipped roofs finished all round at eaves (as shown at left hand of Fig. 76), short trimmer ceiling joists are required to carry the eaves out and to receive the feet of rafters at the ends of the roof. Fig. 83 shows some of these trimmer joists going from the side of the last long joist out over the wall, and carrying the feet of the rafters. The trimming of ceiling joists should be in all cases as described in Art. 389, *ante,* on trimming of floor joists.

434. Bearings and Supports of Ceiling Joists. Different methods of arranging the bearings of ceiling joists on walls and under and against rafters are shown in Fig. 76. Ceiling joists should be further supported (excepting in the case of truss construction, where it is impracticable) by pieces of

timber called *"hanging pieces,"* which extend from wall to wall on top of, and at right angles to, the length of the ceiling joists, and connected to each of the latter by pieces of 2 in. x 2 in. One hanging piece should be provided for joists with spans up to 12 ft., and thereafter two up to spans of 18 ft., the cross sections of the pieces in all cases to be sufficient to give stiffness to the ceiling.

435. Timber for, and Spacing Apart of Ceiling Joists. Oregon is about the best kind of timber for ceiling joists, and is much used, but hard woods such as tallow wood, blackbutt, white mahogany, spotted gum, red mahogany, grey gum, etc., as well as colonial pine, are also greatly used. Ceiling joists are usually spaced 18 in. centre to centre.

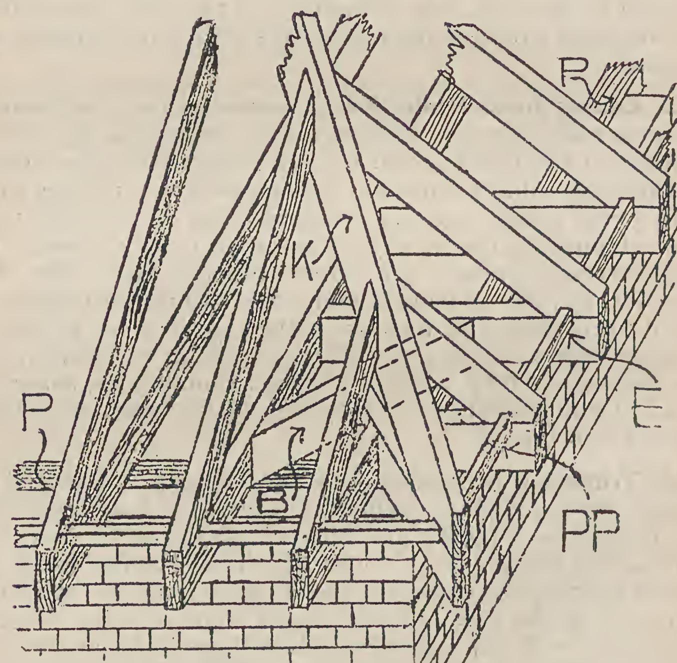


FIG. 83

436. Sizes of Ceiling Joists. For pine joists, 2 in. thick with ½ in. of depth for every foot of span is a good size. A thickness of 1½ in. may be used, in which case the depth must be a little more than when 2 in. thick. If hardwood is used it is best to keep the size about the same as for pine, for, although stronger timber, as before pointed out, it is difficult to get it

seasoned. As regards the depth, it is, however, well to point out that with the eaves finished, as at left hand of Fig. 76, the maximum room span will decide the depth of all the others, for the depths at the eaves round the roof must be the same. If for the sake of economy it is worth while to have the depths different, the joists must be reduced to the same depth at the feet of the rafters to have the eaves the same height all round.

437. Ridge Piece and Ridge Roll. The horizontal piece of timber to which the upper ends of the rafters are secured is called the *ridge piece*. It varies in thickness from 1 in. in small, to 2 in. or 2½ in. in large roofs, the depth being made to suit the size of the rafters. Joints where necessary in the length are made with the scarf joint marked D, Fig. 65. The piece of timber, partly rounded in cross section, shown on top of ridge piece at U in Fig. 76 and 78, is used to dress the lead ridge covering round, and is called the ridge roll.

438. Hip and Valley Rafters. The external sloping edges formed by the intersections of surfaces of hipped roofs are called hips. For an example see K, Fig. 74. To form the hips pieces of timber called *hip rafters* are put extending from the corner of the wall to the ridge (or to the upper point of the roof if there be no ridge), and on to them are cut and secured the upper ends of the short rafters. Fig. 83 illustrates a hip rafter (K), and small rafters (called *Jack Rafters*), together with ceiling joists, etc., of a roof with eaves to be finished as at left hand of Fig. 76. To prevent a thrust on the corner of the building the foot of the hip rafter should be tenoned with a corner timber called a dragon piece, which bisects the angle of the corner of the building, and is held in place by being tenoned and pinned with a cross piece (B, Fig. 83) called an *angle brace*, which is in its turn tenoned into ceiling joists. Where there are no ceiling joists at the level of the plates, as in a collar-beam roof, the angle brace is secured by notching and spiking to the wall plate. Hips are surmounted by rolls, similar to those for ridges, where lead covering is to be used. The internal angles formed by intersections of roof surfaces are called *valleys*. (See D, Fig. 74). A valley is really the reverse of a hip, and the main points of construction are the same, a rafter, called a valley rafter, about the same size in cross section as a hip rafter, being put in to receive the upper ends of the short rafters, but the top of the valley rafter is kept down flush with the top edges of the rafters to allow the valley boarding to meet above it. (See Fig. 84, which shows a cross section of a valley, A being the valley rafter, CR the rafters and B the valley boarding.) The pole plate is the piece of timber on to which the feet of the common rafters are cut.

It is generally about 2 in. x 2 in. in cross section, and is, as a rule, in ordinary roofs let half its depth into the ceiling joists. A pole plate in ordinary roof construction is indicated by E, in Figs. 76 and 83. It will be seen by the latter sketch that the foot of the rafter comes directly over the ceiling joists so that the pole plate does not carry the rafters. In roofs of truss construction the pole plates are much larger in cross section, having to carry the feet of the common rafters, as well as hold them in place. A pole plate in a truss roof is indicated by PP in Fig. 77, and by PP in Fig. 79. Hip and Valley rafters and pole plates are made of pine, oregon being usually used.

439. Purlins are the pieces of timber placed at intervals to support the common rafters. In roofs of truss construction the purlins bear on the principal rafters (having blocks below them at the point of bearing, as shown at S, Fig. 77), and span the distance between the trusses. See part of purlin marked S in portion of queen-post roof, Fig. 80. In roofs of single span, collar beam, and couple-close construction, the purlins are put with ends resting in the gables, if there be such, but the purlins in all cases being supported at intervals along the length by struts. The struts should bear, *not* on the ceiling joist, but on to either cross walls or beams, provided for the purpose, and clear of the ceiling. A purlin, as in ordinary roof of couple-close construction, is shown at S, Fig. 76. The Table XXVIII, by Tredgold, which will suit the demands of ordinary practice, gives the safe scantlings of pine purlin for different spans and various distances apart in roofs covered with slate. Joints where necessary in the length of purlins are made with the halving joint (see H, Fig. 65), the joint, of course, always being over the point of support.

TABLE XXVIII*

Showing Cross Sections of Pine Purlins.

Span in feet.	DISTANCE APART.			
	6 feet.	7 feet.	8 feet.	9 feet.
6	6" x 3½"	6¼" x 3¾"	6½" x 4"	6¾" x 4¼"
7	6¾ x 4	7 x 4¼	7¼ x 4½	7½ x 4½
8	7½ x 4½	7¾ x 4¾	8 x 4¾	8¼ x 5
9	8¼ x 5	8½ x 5¼	8¾ x 5¼	9 x 5½
10	8¾ x 5¼	9¼ x 5½	9½ x 5¾	9¾ x 5¾
11	9½ x 5¾	9¾ x 5¾	10¼ x 6	10½ x 6¼
12	10 x 6	10½ x 6¼	10¾ x 6½	11¼ x 6¾
13	10¾ x 6½	11¼ x 6¾	11½ x 7	12 x 7¼
14	11¼ x 6¾	11¾ x 7	12¼ x 7½	12½ x 7½

* Tredgold.

440. Common Rafters. These are the timbers, supported at their feet on to the pole plate or birds mouthed over wall plate and at their heads against the ridge piece, which carry the boarding or battens and slate or other roof covering material. The methods of cutting feet on to pole plates and heads on to the ridges are shown in Figs. 75, 76, 77, 78, 79, and 83. See also Art. on *Eaves* for further information as to finish at feet in certain cases.

441. Common Rafters are spaced generally 18 inches centre to centre for slate or tile covering, but for corrugated galvanised iron they are, as a rule, put 3 ft. centre to centre. The Table XXIX, gives scantlings of common pine (such as oregon) rafters for various lengths of span, the length of span being the distance between points of support such as pole plates, purlins, and ridges.

In some cases of truss construction, where a galvanised iron or corrugated fibro-cement covering is used, the common rafters are omitted, and the material is put directly on to the purlins, which are in such cases spaced not more than about 3 ft. apart. Rafters should be trimmed in the same manner as joists (see Art. 389, *ante*), round chimney stacks, openings for skylights, etc.

TABLE XXIX

Showing cross sections of pine common rafters for different spans. To be spaced 18 inches centre to centre.

Distance between points of support in feet.	Cross section in inches.
4	3 x 2
6	4 x 2
8	5 x 2
10	6 x 2

442. Boarding, Battens, etc. The roof covering material is secured either to (1) purlins, (2) battens, or (3) boarding. When secured to the purlins the common rafters are, of course, omitted. Battens are strips of timber (usually pine) ranging, according to weight of covering material, from 1½ in. x 1 in. to 3 in. x 1 in. in cross section. They should be spaced apart to suit the tiles, slate, or iron covering, etc., and well nailed to the rafters. Battens (one is marked D) are shown in Fig. 76. The lowest batten should be thicker than the rest. so as to give the bottoms of the slates or tiles a slight upward cast at the eaves. In better kinds of construction pine *boarding*, about

1 in. thick, is nailed on to the rafters, as shown at B, Fig. 78, to receive the covering. In the example, Fig. 78, the boarding is shown as parallel to the ridge, but a better way is to have it diagonally, for it then acts as bracing for the roof. In Gothic roofs, where the underside of the boarding is exposed, it is usual to have the longitudinal joints tongued and grooved, and the edges beaded or V jointed. When boarding is used a narrow strip, called a *tilting fillet* (see Fig. 79), is put at the lowest edge to achieve the same result as the thick batten mentioned above.

443. Roof Gutters. The making of gutters in connection with roofs is done partly by the carpenter and partly by the plumber. The former does the preparatory timber work, and the latter the finishing metal work. Unless the timber work is done to enable the plumber to put the metal in properly, the

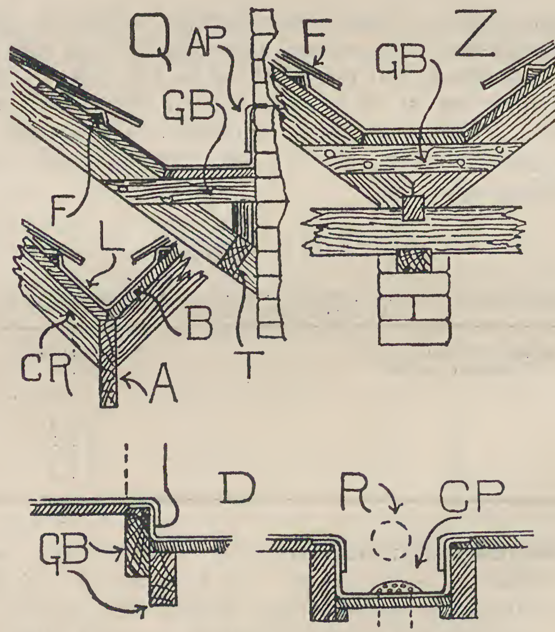


Fig. 84

gutter will not be a success. It will, therefore, be clear that the carpenter must have knowledge of the plumber's work, which is to depend on his work. For this reason the following, though mainly descriptive of the timber work of gutters, necessarily deals to some extent with the plumber's work. Roof

gutters are made at the following places:—

(a) At horizontal lines of intersection of roofs with walls (see A, Fig. 79, and Q, Fig. 84).

(b) Between roof surfaces such as those of a V roof (see Z, Fig. 84).

(c) Behind upper faces of chimneys (see Q, Fig. 84, and at the upper edges of skylights (see Fig. 87).

444. Gutters at horizontal lines of intersection of roofs with walls are made either as shown at A, Fig. 79, which illustrates what is called a box gutter, or as shown at Q, Fig. 84, which is a sketch section of a gutter with one side sloping up with the pitch of the roof. Both of these kinds are used behind parapets or where a wall extends up beyond the eaves. The box gutter A, Fig. 79, is formed with bottom of pine boards about 1 in. thick, which rest on, and are nailed to, pieces of 3 in. x 2 in. called gutter bearers. The latter are spaced about 18 in. centre to centre, and rest at one side on a fillet secured to the pole plate, and at the other on to small studs from the tie beams, and into the wall in the intervals between the trusses or, on to a plate between the trusses, resting on the tie beams. The side of the gutter nearest the roof is formed partly by the pole plate and partly by pieces cut in on top of pole plate, and between the rafters. Box gutters are generally used in roofs or truss constructions, and should be not less than 12 in. wide.

445. The Gutter shown at Q, Fig. 84, has the bottom also formed of boards resting on gutter bearers, but the latter are secured to sides of common rafters at the inner ends. The sloping sides should be of the same thickness as the battens or boarding used on the roof. The gutter Z, Fig. 84, is an example of the type generally adopted for V roofs, though in some cases a box gutter between two pole plates is used. The type of construction shown at Q, Fig. 84, is that used behind chimneys, which, like that at E in the hip roof, Fig. 74, are not at the upper edge of the roof. In all these gutters, excepting those behind the chimneys, and in other cases where the length is very short, what are called expansion joints or *"drips"* have to be made where the pieces of metal meet. When lead is used the drips should be not more than 12 ft. apart. When galvanised iron is the lining material the drips should be about 33 ft. apart. The method of forming a drip is shown at D, Fig. 84. The sketch is a section taken in the direction of the length of the gutter. At the drip the gutter bottom is dropped, if possible, 3 in. but not less than 1½ in., the gutter bearers GB being arranged one lower than the other (as

shown) to allow of the drop, and the edge of the upper bottom is rebated to receive the turn-over of the under lead. The sketch shows drip for a lead gutter; but, for galvanized iron which, by the way, is very much used, the preparation is much the same, the difference in the joints being more in the plumber's than in the carpenter's work. If the lining is to be of lead, the falls in the lengths between the drips should be not less than 1 in., but for galvanized iron, the fall should be much greater, as the iron does not lie so flat. Tilting fillets (marked F in Fig. 84) over which the inner upper edge of gutter lining, or apron flashing, if there be such, should be turned, must be provided in all cases. If tilting fillets are not used the lining must be finished with a bead. At the lowest levels of gutters, "*wells*," or "*cesspools*," are formed, out of which the water is taken by a pipe leading to the down-pipe head outside. These cesspools are usually square in plan, and from 6 in. to 9 in. deep. A section of a cesspool is shown at CP, Fig. 84. As will be seen, the cross sides are formed with extra deep gutter bearers, the bottom being formed of boarding, resting on fillets at sides of bearers. The transverse upper edges are formed just as drips.

446. Eaves, examples of which are shown at H H H, Fig. 74, are the lower, overhanging edges of roofs. The methods of forming them may be put under two heads, though in matters of detail there is much variety:—

(a) Eaves with ends of rafters exposed.

(b) Eaves with ends of rafters boxed in.

The average projection of the eaves is about 18 in.

447. (a) Eaves with Ends of Rafters Exposed. The case of a common roof with eaves of this kind is shown in Fig. 75, in which the rafters are extended for some distance out past the face of the wall, and a board (B), called a *fascia board*, nailed along their lower ends. When a better finish is required the ends of rafters may be planed and also curved, and boarding, with lower faces dressed, put on top as shown in Fig. 76. In this case a second fascia is put along top of wall to cover wall plate, and spaces between the rafters. Sometimes the ends of rafters are left rough and the boarding put underneath. The ends of rafters in truss roofs may be finished as above. (See D D, Fig. 77.)

448. (b) Boxed Eaves. An example of a boxed eave is shown at left hand side of Fig. 76. In this case the ceiling joists are extended for some distance (see also Fig. 83) past the face of the wall, and boarding, called *soffit boarding* (see G. Fig. 76), generally about 1 in. thick, with under face

planed, is nailed under them, the fascia (B) being also nailed to their ends. Boxed eaves in truss roofs are framed up at bottom of common rafters, with 4 in. x 2 in. horizontal firring-pieces as at A, Fig. 77. Boxed eaves are at times made very elaborate with mouldings on fascias, and brackets, or consoles, under the soffit. Boxed eaves may also be formed by fixing the rafters as described in Art. 447, and spiking bearers to the feet of the rafters and let into wall or supported on plate at other ends. The soffit lining is then fixed to these bearers. Redwood makes an excellent timber for eaves work. Eaves when well finished go far to make a house look well, but for city architecture they are not safe on account of the easy passage, in the way of exposed timber, which they offer to fire from one building to another.

449. Dormer Windows. Rooms in roofs are by no means uncommon, but, beyond the fact that the joists must be made strong enough to take the floor weights, there is nothing special in the timber work. The partitions will be described later on. The windows called *"dormer windows,"* which are put in to light these roofs, rooms, or attics, are, however,

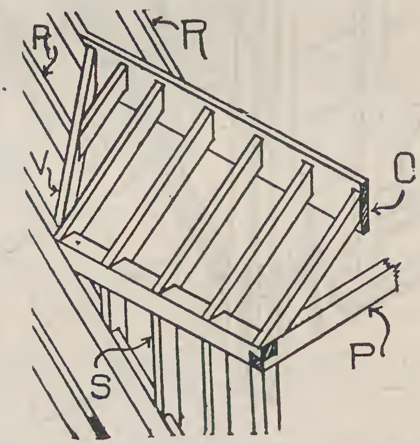


Fig. 85

deserving of a little attention now. The sketch, Fig. 85, shows the skeleton construction of part of a dormer window. R R are the common rafters of the main roof. P is the wall plate of dormer, O the ridge, and V the valley rafter between the two roofs. The studs to form the sides of the projection of the dormer are shown (one is marked S) as halved, on to the common rafter. Fig. 86 shows a lower corner of a dormer in which A is the corner stud, and K the stile on to which a

casement, opening outwards, would be hung. The stile (K) should be put in first, with its lower end housed into the under sill (Q), and the lead apron (L) turned round it and over the fillet (F) on under sill, before the upper sill (H) is put in. In this sketch, Fig. 86, the sides and portion of front of dormer are shown as covered with weatherboards, but slates, lead, zinc, muntz metal, tiles, and shingles are used at times for covering.

450. Skylights. A skylight is a window put in, and having the same, or nearly the same, slope as a roof. They are sometimes adopted instead of the dormer, described in last article,

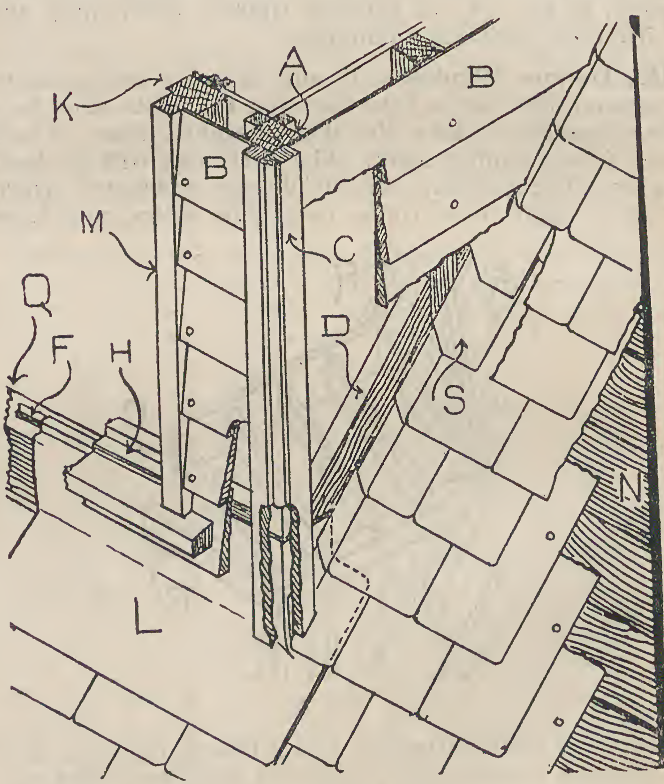


Fig. 86

for attic rooms, where otherwise sufficient light is not obtainable. A section of a skylight is given in Fig. 87. T T are the trimmers to the rafters; G the lining board, which goes round the opening, and on to which the sash is fastened. The sashes

are made from 2 in. to 3 in. thick, the glass being let into grooves at top and two sides, but passing over bottom rail, which is of lesser thickness than the other parts of the sash. The lining should be tongued into the sash at top and sides, as shown, and both the lead of upper gutter and aprons at the sides should pass over the tongues. A groove to stop the water running down should be put on the top under side of sash, as illustrated in the sketch. A fillet (H) is sometimes put on at the upper under edge as a further protection against water at the top joint. A fillet with a grooved top edge to take the inner edge of the lower lead apron should be put, as at J, Fig. 87. This small gutter takes off to the sides the water of condensation, which collects at this under edge. In cases of important rooms and stairs halls, an under framework, generally of an imposing design and filled with stained glass, is put under the skylight proper at the level of the ceiling, so as to overcome the usually unsatisfactory appearance of the under side of the skylight.

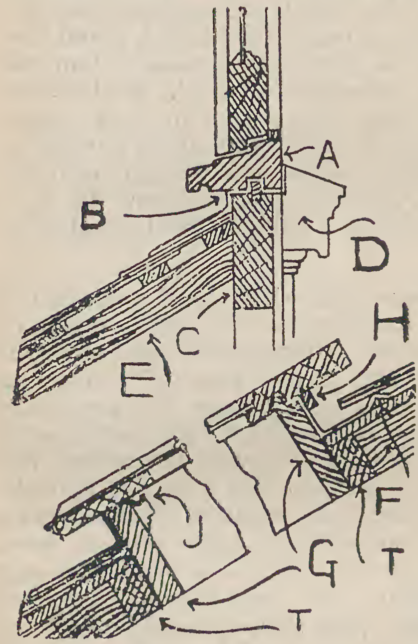


Fig. 87

451. Lanterns. Top lights are sometimes made by elevating part of the roof at the ridge and putting in sashes, vertically, or slightly sloping, between the part so elevated, and the lower portion. These lights are called *lanterns*. When building them the greatest care must be taken to have every possible guard against the inroads of the weather, for, like skylights, if not properly made, they give the greatest trouble. The upper sketch, Fig. 87, gives section through the sill at one side of a lantern. C is the plate, or under-sill, to which the tops of the common rafters E are cut and secured. A is the sill of the lantern, which should not be put into place until the upper part of the lead apron is taken over a fillet, which projects from upper edge of plate C. The bottom of the sill A should

be grooved to take this fillet with the lead over. The lead apron should, if possible, be taken right through and turned up at the back of the sill A. If the lantern is on a hip roof (in which case the sill will be returned at the ends), particular care should be taken that the fillet goes right to the angle, and that the lead is taken out over it, and, further, that the lead is not joined just at the angle, but that it is in a single piece for at least 18 in. on each side of corner. The sill A should be grooved on under side near the front. The roofs of lanterns are not much different from ordinary roof work. If the wind is to be feared, the lantern may be secured by iron straps, extending from sill A to plate C. D is a moulded cornice to cover the joint of the two sills. Sometimes lantern construction is adopted to provide a covered look-out from the roof, in which cases floors are put in at a suitable level to allow of sight from the windows.

452. Flats. It often happens that where yard room is not obtainable the roof is made flat so as to serve the purpose of a yard. At other times the space between two parallel ridges is bridged over with a horizontal surface to avoid a gutter in between, or to provide space for a room. Again, it is a common thing to have roofs of bay and oriel windows and other small areas finished with parapets and covered with flat roofs. The flats are made much on the same principle as a floor. If the space above is to be a yard, the joists must be strong enough to carry the weight. If the horizontal space is only to serve as a roof, it will be enough to have the joists strong enough to carry the covering material. The joists should be spaced 18 in. centre to centre, and the upper surface should be formed with stout boarding, well seasoned, and brought to a fair upper surface. The fall of the flat should be not less than 1 in. in 10 ft. In all cases the joists should be supported by bearers or purlins at frequent intervals. Where the lower edge of flat is behind a parapet, a box gutter, as at A, Fig. 79, should be provided. Where metal is used as a covering, rolls must be fixed. (See description of plumber's work later on as to spacing of rolls.)

453. Roof Ventilators. These may be triangular, or other shaped frames with louvres, the latter being inclined boards ranging in thickness from ½ in. to 1 in., and each covering the other to some extent as shown at C, Fig. 89. The vent frames are placed in a variety of ways. Sometimes they are built in little gable-like projections from the main roof, in which cases the construction is much after the style of that for dormer windows, as shown in Fig. 85, the vent frame with louvre being put in the front. In cases where the roof is

hipped the main ridge is extended past the point for some distance, and the side slopes of the roof carried on also, thus forming triangular openings at ends, which are filled with louvres. Again, a by no means uncommon way is to put a lantern at top of roof, but instead of putting in the glazed sashes, louvres of glass are put in between the studs. Another way where there are gables is to put the ventilator frames in the brickwork. In all cases where put in as projections from the roofs, the care described as being necessary for sills of dormers and lanterns should be taken.

454. Barge Boards and Finials. In cases where the gables are not carried up with parapets, it is usual to project the roof over the walls for some distance, and finish the edges with timbers called *barge boards*. Fig. 89 shows at A and B, front and cross section, respectively, of a barge board. The wall plate, purlins, and ridge are extended out past the face of the wall to carry one, two or three common rafters as the demands of the projection may require. The barge boards, which vary in thickness from $1\frac{1}{2}$ in. to 3 in., are nailed on to the outermost rafters. At the head they are either mitred together or tenoned into a vertical piece called a *finial*. In the example shown in Fig. 89, the upper outer edge of board is moulded and the slates shown as projecting slightly beyond the moulding. Barge boards are made in a variety of ways, and in different styles of design ranging from the very plain to the most elaborate. The example in Fig. 89 is a plain board, with mouldings near the upper edge only, and fitted with a turned finial at the head. In some cases the boards are cut and carved, producing curves of a flowing nature, and often enough resulting in effects very like wedding-cake ornament. In other cases the boards are framed up with panels, and sometimes the whole is made to look like an ornamental truss with tie beam struts, etc.

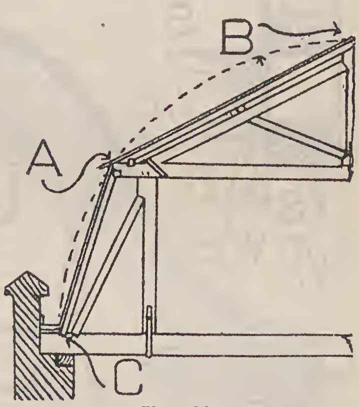


FIG. 88

455. Mansard and Curved Roofs. A slight notice of these, to some extent uncommon, roofs is all that is possible on account of the limits of space. Fig. 88 shows half of a truss for a mansard roof. To get the form proceed as follows: Draw

a line for top of tie beam. Mark on this the toes of common rafters (one is marked C in Fig. 88). Draw a semi-circle extending from toe of common rafter on one side to toe of common rafter on other side. Divide this semi-circle into 5 equal parts. The line from toe to first point of division on each side (A is the point in the half shown) gives the shape of lower part of roof. The line from first point of division on each side to top of semi-circle will give shape of top of roof. The top slope in sketch is from A to B.

456. The Mansard form of roof is very good where a story in the roof is needed. The truss is framed up on principles similar to those described for other trusses. The eaves may be finished in any of the ways shown in sketches, Fig. 76 and 77. The walls are, however, generally carried up as parapets, as shown in Fig. 88.

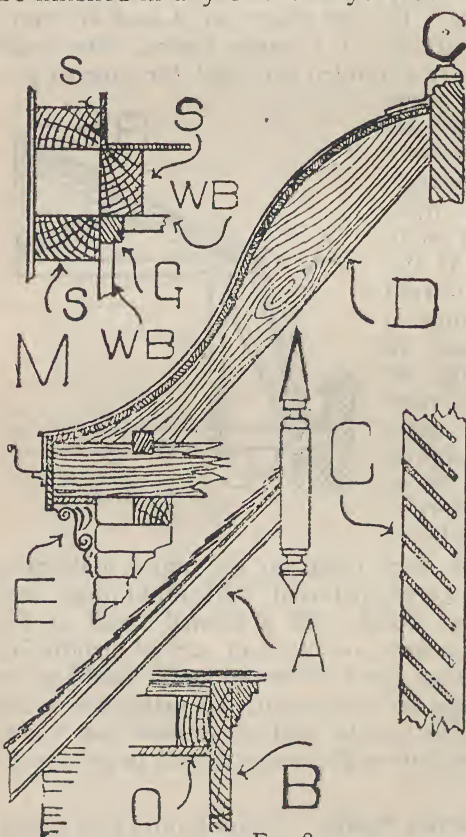


Fig. 89

Large roofs of curved form are nowadays made almost without exception of steel, but roofs of ornamental form for towers, turrets, small pavilions, etc., may be built with economy, out of timber. These roofs are generally hipped, and range in plan from rectangular to all sorts of polygonal forms, and in vertical section from semi-circle to ogee. The way to build them is as follows:—The hip rafters are cut to the curve required out of timber which may be from $1\frac{1}{2}$ in. to 2 in. according to the length. If outside appearance only is of consequence, the undersides of rafters are left straight, so as to preserve as much strength as possible (see D, Fig. 89); but when the inner side of roof is also to show curved,

the curve must be cut on underside of each rafter as well. Intermediate rafters are cut with curves less flat (these curves should be properly projected by geometrical methods), so that external edges of intermediate and hip rafters may, in each face, lie in the one plane of curvature. Some of the intermediate rafters will cut on to the hips as jack rafters, and the length of each will be part of curves of a full intermediate rafter. The sketch D, Fig. 89, shows an intermediate rafter for a small roof of ogee external form, all with rafters coming to a point at the top. The rafters are generally covered with narrow boards on to which the metal or slate covering is fixed. The sketch is simply a diagram to illustrate the principle of construction, and the parts are not in proportion.

STUD WALLS AND PARTITIONS

457. **Framed or Stud Walls** are constructed with uprights of light scantling spaced at equal distances apart, and mortised into plates at bottom and top, with an outside covering of weatherboards or asbestos cement sheets, and an inside lining of either boards or plaster, etc. The external covering is sometimes of shingles, and even slates or tiles are on rare occasions used.

458. **Studs.** A sketch of a front view of part of skeleton of a stud wall is shown at A, Fig. 90. The studs may be either of 4 in. x 2 in. pine or 4 in. x 2½ in. hardwood, and should be spaced 18 in. centre to centre. Studs at corners should be square in cross sections. Openings (see Fig. 90) for doors and windows are trimmed just as joists or rafters, but the tenon need only be a simple one. Wherever possible diagonal braces (H on sketch) should be put in. The braces may be 3 in. x 1 in. in cross section, and should be housed in flush with outer edges of studs.

459. **Plates.** If supported on brick foundation walls the lower plates may be of 4 in. x 3 in., but if supported on piers, or piles, the cross section should be 5 in. x 4 in. Hardwood should always be used for lower plates. Brick piers to support plates should not be less than 9 in. x 9 in. cross section. If piles are used, the diameter must be not less than 9 in., and they should be coated with tar before being put in the ground. Capping pieces of galvanised iron should be put on tops of piles, as shown at R, sketch D, Fig. 90, before the plates are laid, but if the foundation consists of brick walls or piers, a slate damp-course must be put in. The *upper plates* are usually 4 in. x 3 in.

460. Weatherboarding is composed either of—

(1) Feather Edged Boards, or

(2) Rusticated Boards

461. Feather Edged Boards are about 1 in. thick at lower edge and diminished to about ¼ in. at upper edge, the width being 7 in. (See sketches of cross sections W B at C and D, Fig. 90.) They are usually made out of hardwood (tallow

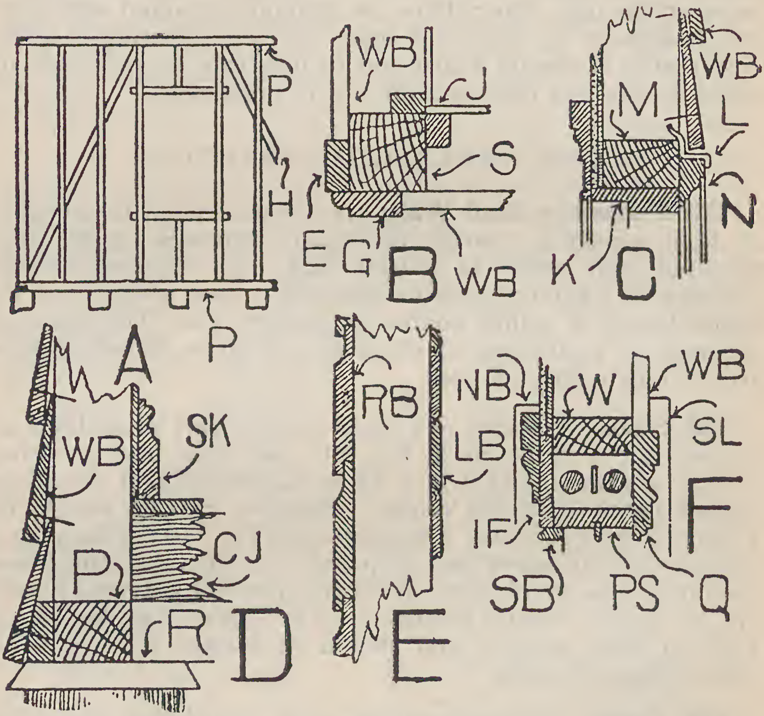


FIG. 90

wood and red mahogany being the best kinds for the purpose), but pine both colonial and imported is also used. These boards should be fixed with a lap of 1½ in., and only one nail put from each board into each stud, as shown in the sketches, Fig. 90.) They are usually made out of hardwood (tallow The lower external edges are shown sharp in the sketches, but there is no need to have them this way, for they may be either chamfered or beaded, if desired. A tilting piece should be nailed along the plate to give the lowest board a bell cast as shown at D, Fig. 90.

462. Rusticated Weatherboards. A sketch, showing cross sections R B of this kind of board is given at E, Fig. 90. As will be seen, the lower edge of each is rebated to receive the top edge of board next underneath. The boards are 9 in. wide, and 1 in. thick up to where the gradual reduction commences to form the top edge. Like the other boards they should have only one nail put into each stud.

463. Rusticated Weatherboards are made out of kauri pine or American redwood, the latter being much the best. *Heading joints of all kinds of weatherboards should be broken.* In the case of these boards the lowest cannot very well be tilted, as shown at D, Fig. 90, but to get the rain water clear the following arrangement is adopted: A piece 6 in. deep, with its top edge the same, as those of rusticated boards, and a bottom edge about 2½ in. thick, with a drip groove, is nailed with its bottom edge at the level of bottom of plate and its top edge fitted into the rebate of the lowest weatherboard.

464. Method of Finishing Corners of Stud Walls. A horizontal section of an external corner of stud walling is shown at B, Fig. 90. S is the corner stud which, as before remarked, should be square. W B are the weatherboards overlapping the stud for a little distance and stopped against vertical pieces (E and G) called stops. As will be seen, one stop over laps the other, and is moulded so that an ovolo is formed at the angle. Fillets are generally nailed on inner faces of stud, as shown, to provide bearing and nail hold for inside linings. An isometric sketch of finish of a weatherboard corner is given in Fig. 86, in which A is the corner stud and C one of the stops, B B being the weatherboards. For the method of finishing internal corners see M, Fig. 89, in which S S S are the studs. W B the weatherboarding, and G the stop against which the weatherboards are butted.

465. Methods of Finishing Heads of Openings in Stud Walls. C, Fig. 90, is a vertical section of the head of a door opening; M is the head which, as before noted, should be tenoned into adjacent studs as a trimmer; K is the jamb lining head; N the outside stop; and W B the weatherboards. With a view to keeping out the weather a lead flashing should be put behind the weatherboard and against the head, and should extend out over and down face of stop for a little, as shown at L. A window head would be finished in the same way as regards the lead flashing.

466. The Window Sills in Stud Walls to be properly fixed should be put in as shown at B, upper sketch, Fig. 87; that is to say, a lead apron should be put in over fillet on trimmer

sill, and turned up a little at back of window sill, care being taken that the apron is also turned up beneath ends of window sill and studs. As a rule, however, the lead apron is not put in, and indeed in the majority of cases the trimmer sill is left out altogether, the window sill being housed into studs. The latter way is very slipshod, and allows the ingress of the weather. The front of sill is (whatever the method of fixing) generally allowed to extend for some distance on to face of weatherboards. (See Fig. 86.)

467. Windows in Stud Walls. A horizontal section of a box frame set in relation to stud W, and weatherboards WB, is shown at F, Fig. 90. As will be seen, the outer facing Q of box frame serves also as a stop for weatherboards and an outside architrave.

468. Sides of Openings in Stud Walls are finished much the same as the heads, the omission of the lead flashing being the main difference, but it will be remembered that the weatherboards at the sides abut, end on, to stops or outside architraves.

468a. Asbestos Cement Sheets, which are used extensively for an external wall covering, are manufactured from asbestos fibre and Portland cement by specially designed machinery. It is rustproof and consequently is proof against sea air. It is available in sheets ranging in size from 10 ft. x 4 ft. to 10 ft. x 2 ft. and 3/16th in. thick for external use and 5/32nd in. thick for internal use. The sheets are nailed to the studs, the joints being covered with timber cover battens on asbestos cement cover strips.

469. Inside Linings of Stud Walls. Stud walls are lined on the inside with either—

(1) Laths and plaster,
(2) Metal plates of ornamental pattern,
(3) Narrow, thin, lining boards.
(4) Fibrous plaster,
(5) Asbestos cement sheets,
(6) Wall boards.

Of the first two kinds of lining the steel sheeting is far the better, for, not only is it fire resisting, but it is also not affected by shrinkage, as is plaster. The sheets are nailed to battens put on to suit. Lath and plaster work will be dealt with later on. The lining boards are generally ½ in. thick and 4 in. wide, with tongued and grooved edges, and are worked so as to show either a bead or a V joint at meeting edges

when fixed. Lining boards may, however, be obtained 6 in. wide, and both the latter and the 4 in. boards can be got of greater thickness than ½ in., if desired. L B at E, Fig. 90, shows sections of narrow lining boards. They are nailed with two nails to each stud. Heading joints should be broken.

Wall linings of fibrous plaster and wallboards are described in a later chapter. Asbestos cement sheets are sometimes used for lining the internal surface of stud walls, and are 5/32nd in. thick. The sheets are nailed to the studs and the joints covered with timber battens on asbestos cement cover strips. Sheets either plain or marked out as wall tiles with a glazed surface are available for use in rooms such as bathrooms and kitchens. Special mouldings can be obtained to cover the joints. The surface is lasting and will withstand severe washing.

470. Stud Partitions. Stud walls are sometimes used in both brick and timber buildings and in roofs as partition or dividing walls. For such purposes the studs, plates and bracings are similar to those described in preceding articles on external stud walls, the main difference being that the lining, whether lath or plaster, boards or metal sheeting, is put on both sides. Stud walls and partitions should be kept at least 4½ in., but, if possible, 9 in., clear of fire places and flues.

BALCONIES AND VERANDAHS

471. A Balcony is a railed-in platform projected from the face of a wall, and supported by cantilever brackets, or consoles. In some cases balconies are formed of stone or brick in cement corbelled out, but only those built of timber are to be dealt with here. The sketch at A, Fig. 91, shows section of a typical case of balcony construction. C L is one of the cantilevers which are either part of the floor joists extended out, or are separate pieces put in through the wall and extended into the inner floor for some distance, and well anchored with spikes to the floor joists. The cross section of the cantilevers at face of wall is about 9 in. x 3 in. for a balcony, about 4 ft. wide, and they are spaced about 36 in., centre to centre. The cantilevers are generally cut and shaped somewhat like the one in the sketch, though, of course, there is no rule to limit the design, except that too much must not be cut away. Sometimes the cantilevers are put in rough, and the under surface of the balcony is formed with boarding nailed on to underside of the cantilevers. When this is done sham *cantilever brackets or consoles* of elaborate design are put underneath for the sake of appearance. The joists are pieces of

small cross section (about 3 in. x 2 in. or 4 in. x 2 in.) arranged parallel with face of wall and housed about $\frac{1}{2}$ in. into sides of cantilevers. The joists should be put in so that, when the floor boards are on, there will be a fall from wall to front edge of balcony to get the water off quickly. The joists being put in as shown in the sketch will provide for the floor boards being at right angles to face of wall. This is mentioned, because sometimes the joists are omitted and the boards put on cantilevers and necessarily parallel to face of wall. This is a

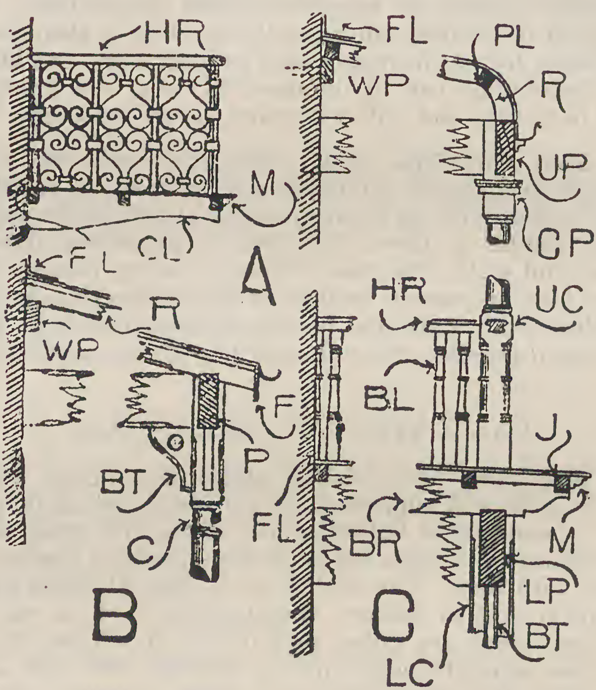


Fig. 91

very bad style, for the water will not run off across the longitudinal joints of the floor boards, even though a fall, by sloping the top edges of the cantilevers, be provided for. Cornice mouldings, as at M, Fig. 91, are put along the front side of outer joists, in case of construction as shown, or (when the under surface is formed with boarding) along a fascia put on ends of cantilevers. In the style of construction shown, the edges of joists would be beaded or stop-chamfered. The floor

boarding would be tongued and grooved, and laid much the same as described in Art. 394, *ante*, but, if exposed on the under side, the under faces would also be dressed and the longitudinal edges beaded or V jointed; and in laying, the tongues and shoulders of joints should be white leaded.

In the example shown the railing is of ornamental iron-work, which should be wrought rather than cast. The railing is, however, very often composed of pieces of timber about 2 in. x 2 in. or, of balusters, as at B L, sketch C, Fig. 91. H R is the handrail, which (whether the under portion be of timber or of iron) is usually of timber.

The joint (FL, sketch A, Fig. 91) of floor with walls in all cases of timber floor should be flashed with 5 lb. lead. Balconies are often roofed in, but this is done in the same way as hereafter described for verandahs, and so need not be touched on at this stage.

472. A Verandah is a roofed space adjoining and at side, or sides, of a building to provide shade and protection from the weather and for use as a kind of outdoor sitting-room. The outer sides are generally left open. Properly speaking, the verandah is only of one story, but with houses of more than one story it is very common to have the verandah also a double-storied structure. The verandah is an essential in Australian domestic architecture on account of the climate, which renders shade to rooms necessary. It is, moreover, a feature which, if well designed and well constructed, adds much to the appearance of a house. The street verandah, or awning, used to cover the footpath in front of shops, and which is so common in Australian city and town architecture, is, however, another matter altogether, for it is very difficult to get a good effect with a structure so foreign to the styles of architecture used for the street fronts. The trouble is intensified, too, by the very flimsy construction adopted, as a rule, for street verandahs. Shade for the shop front is, of course, just as necessary as for rooms of private houses, and, until something better than the street verandah is evolved, it will have to be built; but the construction should at least be good. Recently a very satisfactory method of constructing street awnings has been adopted. The roof is supported either by cantilevers projecting from the wall, or by inclined suspender bars, thus doing away with posts.

473.—One-story Verandahs. The sketch at B, Fig. 91, shows section of a verandah roof of lean-to form. The rafters (R) are supported with upper ends on a wall plate (WP), and lower

ends on a beam or plate (P). The wall plate is usually 4 in. x 2 in. in cross section, is beaded or stop-chamfered on exposed edges, and is bolted to the wall with bolts ½ in. in diameter, which are spaced about 36 in. apart. The outer beam or plate is generally about 9 in. x 3 in. in cross section, with beaded or stop-chamfered lower edges, and carried on posts which are spaced at intervals of about 10 ft. In cases where there are no end walls of brick or stone, the plate is returned at the ends (as shown by the sketch), the joints at the corners being made with mitre and dovetail. Joints where necessary in the lengths of plates are made over bearings with the scarf shown at D, Fig. 65. Sometimes a small plate, or frieze rail, as it is called, is put about 12 in. or 18 in. below the plate, and its ends housed into the posts, the space between it and the upper plate being filled with turned balusters. Roofs of verandahs are exceedingly diversified in form, ranging from the simple lean-to to the ogee of pronounced curve. The form known as "bull-nose," shown in upper part of sketch C, Fig. 91, is sometimes used. In these cases of curved form the rafters are cut as required out of timber about 2 in. thick and the purlins (PL) housed into their sides. In the very common work the rafters and battens, or purlins, are left out altogether, and the roof formed of corrugated galvanised iron in sheets (straight or curved as required) fastened at wall plate and outer plate; hip and valley rafters (if the roof is of a form to require such) only being put in. This is a style of construction which cannot be recommended, as it is very flimsy. The under surface of roof should be lined with boarding, put either on the under or upper edges of rafters; if the latter way, the rafters must be planed, and edges either beaded or stop-chamfered. If tiles, which require fastening from under side, are used, the lining boards must be put on the under edges of rafters. Lining boards have been dealt with in Art. 469, *ante*. The ground floors of verandahs are either of stone slabs, concrete with upper surface of cement rendering, or paving tiles, or timber. If the latter the construction is the same as for other ground floors (see Art. 378, *ante*), except that the joists must be parallel to the wall so as to have floor boards at right angles to the building, for the reason pointed out in the preceding article. The posts may be of iron or timber. If of the former, the wretchedly over-ornamented types of cast iron posts, or columns, as they were called, which have become so common in Australian house-building, should be avoided, and a sensible design, more in keeping with the nature of the material, adopted. Timber is, however, under ordinary circumstances, the most suitable for verandah posts, for even when worked so as to be ornamental this material is the cheapest. Verandah posts of timber

are made out of pieces ranging from 4 in. x 4 in. to 8 in. x 8 in. in cross section, about 5 in. x 5 in. being the size most generally used for verandahs of ordinary houses. The top of the post is generally cut out to allow of plate passing through it. In the plainest designs they are simply planed up and stop-chamfered on the edges. The general practice was, however, to have them with portion of their length turned, circular, with plain cylindrical or vase-shaped intervals, and mouldings, the lower and top parts, and such portions as may receive abutments of handrails being left square. A better treatment, but, of course, more expensive, was to cut the mouldings and curves in on each side, as shown in the upper part of the post in sketch, Fig. 69. As far as possible, all mouldings and other ornamentation should be cut into, and not planted or fixed on to the post, so that the weather shall have as little opportunity as possible to cause decay. In this respect the verandah post is different to the story post, described in Art. 376, *ante*, for the story post generally carries a heavy floor or wall, and there is consequently a reason for not reducing the cross section in any way. Moreover, the story post is generally inside, whereas the verandah post is not heavily weighted, and is exposed to the weather. It must be mentioned, however, that the above reasons notwithstanding, cap mouldings planted on, as shown at C P, sketch C, Fig. 91, were very commonly used. Brackets made of timber about 2 in. thick, and something like the form shown at B T, sketch B, Fig. 91, were sometimes put in the angle between upper part of post and plate. Timber verandah posts are illustrated at C, sketch B, and at L C and U C, sketch C. in Fig. 91. In some cases verandah roofs are supported by brick or stone piers, either extending up to the plates, or carrying arches, and in most cases with the best possible results, both constructively and aesthetically.

474. Two-story Verandahs. Structures of this kind are much used in houses of more than one story. The construction is much the same as that described for the one-story verandah in the last article, the chief difference being the addition of a first floor, which is put at or about the level of the first floor of the house. This floor is composed of bearers, joists and flooring boards, and the whole is supported by a beam or *"lower plate,"* as it is called. The lower plate is generally about 12 in. x 3 in. in cross section, and is worked and jointed in itself, and at post and at angles in the same way as described for plates of one-story verandah. The bearers vary in cross section from 6 in. x 3 in. for 6 ft. wide, according to the width of the verandah. They are spaced apart at distances ranging from 36 in. to 48 in., one end bearing in wall and the other

housed into top of plate. In each case they should fall towards the plate to allow for fall of flooring. As a rule, the bearers are left exposed, and are planed up, and the lower edges stop-chamfered or beaded, the ends being cut, as shown in the sketch, or covered with a fascia and mouldings. Sometimes, however, they are left rough, and a ceiling of lining boards is put on to their lower edges. In the case of the latter, intervening ceiling joists are required, as the bearers would be spaced too far apart to carry boarding. In some cases panelling is put on as ceiling. The floor joists (J) and flooring would be as described in Art. on balcony floors, but the joists would not be less than 4 in. x 2 in. in cross section. The two-story verandah is sometimes called a verandah and balcony, but this is hardly a correct term, for the upper part does not answer the definition of a balcony. The floor boarding would be of similar description, and laid in the same way as described in Art. 471, *ante*, for balcony floors. In the example sketch C, Fig. 91, a small cornice moulding (M) is shown put along the outer face of the outer joist and under the outer ends of the floor boards. A railing either of timber, or of iron work, is put round between the posts. In the example shown the railing is formed of 2 in. x 2 in. turned balusters (B L) spaced about 2 in. apart, with a timber moulded handrail (H R) on top. The roof would be the same as for a one-story verandah, all the parts being called by the same names, as in Art. 473, *ante*, except the plate which is known as an *upper plate* (U P), to distinguish it from the plate (L P).

475. Timber for Balconies and Verandahs must not only be able to stand exposure to the weather, but also must be capable of being easily dressed, for, as shown in the preceding Articles, the timber work of these structures is nearly all planed and otherwise worked. The following is a list of timbers which are suitable for the various parts, but, of course, the questions of supply and cost govern this matter to a large extent, and for these reasons local timbers are often used, the fact, notwithstanding, that they are not the best for the purpose:—

Ground Floor: Any good hardwood.

Upper Floors: Colonial Beech, Tallow wood, Oregon, Colonial Pine.

Bearers and Joists: Colonial Beech, Tallow wood, Oregon, Colonial Pine.

Flooring Boards: Colonial Beech Tallow wood.

Posts: Colonial Beech, Tallow wood.

Plates: Oregon Pine, Colonial Pine.

Rafters: Oregon Pine, Colonial Pine.

Mouldings, Fascias, Handrail, Balusters, etc.: Colonial Beech, American Redwood, Oregon Pine, Baltic Pine, Colonial Beech, Tallow wood.

N.B.—Hardwood may be used for plates and rafters, but the pine timbers are the best.

FENCING AND GATES

476. Fencing may be divided into four kinds as follows:—

(1) (a) Split posts, rails, and split palings,
(b) „ „ „ sawn
(2) Sawn posts and rails and sawn palings.
(3) Dressed posts and rails, and picket battens.
(4) Ornamental fencing.

477. Split Post, Rail, and Paling Fence. This is a very rough, but nevertheless, very durable and serviceable kind of fencing. The posts (about 9 in. x 6 in. in cross section, corner posts being 9 in. in diameter) and the palings about 1 in. thick and from 4 in. to 6 in. wide) are simply pieces split from the tree. The posts are sunk from 30 in. to 36 in. into the ground and spaced from 8 ft. to 9 ft. apart, and the rails, of which there are generally three tiers, are tenoned into them, as shown at A, Fig. 92, which illustrates a fence of this kind. The palings, of which some are shown in position in the sketch, are nailed with two nails into each rail. The lower ends of the post should be charred prior to being put in the ground. The (b) kind is the same as above with the exception that the palings, instead of being split, are sawn pieces ranging from 4 in. to 6 in. wide and about ¾ in. thick. This makes a better-looking fence. A safeguard against the palings being easily knocked off is provided in the form of galvanised iron-hoop bands nailed along on the outside of the palings at the level of the rails, and passing through the mortises in the posts, the width and gauge of the iron hoop being about 1¼ in. and 16 respectively. Whether the palings be sawn or split, they should be fixed so that the tops make a continuous and perfectly-level line. Sometimes where it is only a question of fencing in a paddock for cattle, or a field, the palings are omitted, and the fence consists of posts and rails only. Again, in the case of the latter style of fencing being adopted, it is not an unusual thing to thread lines of 6-gauge galvanised iron wire through the posts at levels midway between the rails, the wire being strained as tightly as possible.

478. Sawn Post, Rail, and Paling Fence. In this kind the timber is all from the saw-mill. The posts may be from 5 in. x 3 in. to 6 in. x 4 in. in cross section, corner ones being square, the sinking into the ground and the spacing apart being about the same as for split fencing. The rails, of which there should be three tiers, are either 3 in. x 2 in. or 4 in. x 2 in. in cross section, and they should be neatly tenoned into the posts, as shown at B, Fig. 92. In this kind it is advantageous to have the rails long enough to pass two spaces, and to arrange them so that the joints (which, of course, come at the mortise in the posts) will be broken, that is to say, two joints at one post, one joint at the next, two again at the next, and so on.

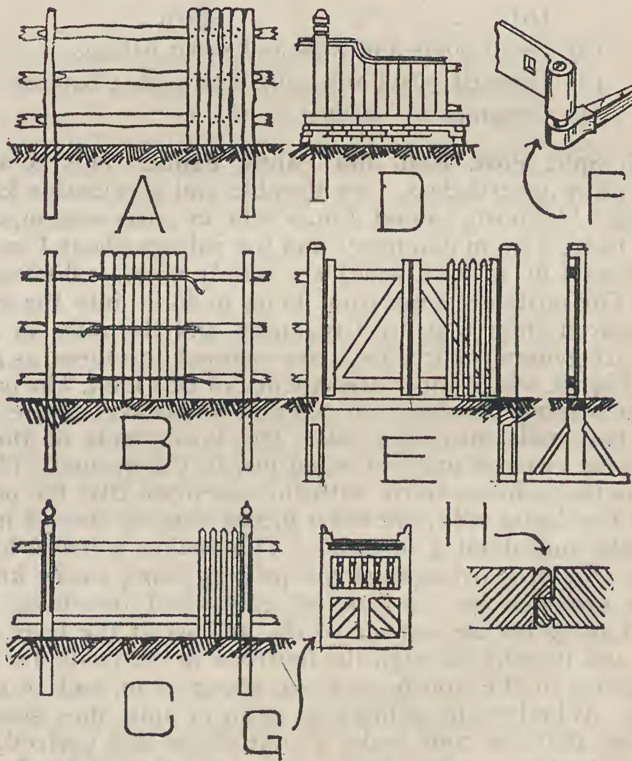


FIG. 92

It is necessary in this kind of fencing to tar the ends of the posts which are to go into the ground. The palings may be as described in last Article, *i.e.*, pieces 4 in. to 6 in. wide and about $\frac{3}{4}$ in. thick, or they may be composed of feather-edged weatherboards, the latter kind being very suitable for fences

enclosing spaces about houses, on account of the privacy which they secure, there being no crevices as in the case of sawn palings. The weatherboards should be fixed vertically with a lap of about 1½ in., and only one nail from each board into each rail. It is difficult to get sawn palings thoroughly seasoned, consequently they shrink in the width after being put up, and ugly spaces or crevices occur. To guard against this it is a good plan to nail the palings temporarily, *i.e.*, secure them without driving the nail right into position, and allow them to remain for some time to give them a chance to shrink after which they can be removed and re-fixed close together.

479. Picket Fence. In this kind the posts are about 4 in. x 4 in. in cross section, planed on the surface, with the edges top-chamfered, sunk about 2 ft. 6 in. into the ground, and spaced about 8 ft. or 9 ft. apart. There are only two tiers of rails, the cross sections of which latter ranges from 3 in. x 2 in. to 4 in. x 2 in., or triangular 5½ in. x 4 in. x 4 in., the latter being called "arris" rails. The rails are planed up on all faces and tenoned into the posts. In the case of an arris rail the large face is put for nailing to. The pickets are battens 3 in. x 1 in. in cross section, planed up on all faces, finished with rounded or turned heads, and nailed to rails so as to be about 2 in. apart. (See sketch C, Fig. 92.)

480. Heights of Fences are as follows:—

Split posts and rail fence ..	5 feet.
Sawn post and rail fence ..	6 feet.
Picket fence	4½ feet.

481. Timber for Fencing. The various kinds of hardwood noticed in Art. 279 to 304, *ante*, make excellent material for posts and rails. The sawn palings should, however, be of tallow wood or blackbutt. The weatherboards should be of tallow wood, red mahogany, or blackbutt.

482. Gates. An ordinary gate, for an opening about 7 ft. wide, such as is used for a vehicle entrance in a fence, is shown at E., Fig. 92. As will be seen, it is composed of two frames or leaves, each of which is composed of two vertical side pieces, two cross pieces, a diagonal brace, and a covering or sheeting of batten pickets. The vertical side pieces and the cross pieces are called stiles and rails, respectively. The rails should be tenoned into the stiles, and the joints white leaded and secured with wedges and pins. When the pickets are nailed on their outer faces should be flush with the outer faces of the stiles. To accomplish this the rails and braces are

made less, by as much as the thickness of the pickets, than the stiles. To obtain the greatest good from the braces they should be put in so as to go upwards from the end of the lowest rail nearest to the post on which the leaf is hung. The two centre or meeting stiles should be rebated and beaded to fit each other (as shown by cross section at H, Fig. 92). Sometimes, instead of working the rebates and beads on the stiles, stop beads are nailed on so as to serve the same purpose. The sheeting or covering of the leaves may be 4 in. x 1 in. or 6 in. x 1 in. T and G and B (or V jointed) boards instead of the pickets shown in the sketch.

483. The Posts to which the gates are hung should be stiffened at the ends in the ground by being tenoned into horizontal cross pieces, or *sole plates,* and braced with struts, as shown in the sketch E, Fig. 92. The depth of the posts in the ground should not be less than 3 ft., and, like fence posts, this submerged part should in every case be well coated with tar. A piece, called a sill, should be put in at the level of the bottom of the gates between the posts as shown in sketch. The best kind of hinge for suspending the leaves is that known as a *"hook and eye hinge"* (illustrated at F, Fig. 92).

484. The following are the sizes generally adopted for the various parts of the gate shown at E, Fig. 92: Stiles, 4 in. x 3 in.; rails, 4 in. x 2 in.; braces, 4 in. x 2 in.; pickets, 3 in. x 1 in.; posts, 8 in. x 8 in.; sole plates, 8 in. x 4 in.; struts, 4 in. x 3 in.; sill piece, 9 in. x 6 in.

485. Small Gates in one leaf for openings about 3 ft. wide are called wicket gates. One is shown at G, Fig. 92. In this case the stiles and rails would be about 4 in. x 4 in. in cross section, the lower panels being filled with 4 in. x 1 in. tongued and grooved beaded boarding placed diagonally and held in grooves, the upper part being filled with 2 in. x 2 in. turned balusters, housed at bottoms and tops into the rails, and the top rail being surmounted by a moulded capping piece. As a rule, however, wicket gates are made just as one leaf of the double gate described in Art. 482, *ante.*

486. Timber for Gates should be as follows:—Posts: Hardwood of good quality such as ironbark, tallow wood, red or white mahogany, grey or red gum, and turpentine. Leaves: Oregon pine, baltic pine, or, where these cannot be got, good colonial pine.

487. The Gate shown at G, Fig. 92, is a very plain example and necessarily cannot be taken as representative of the field of variety in style open to the designer, but, as far as the

principles of construction are concerned, the plain example is fairly typical of gate structures, for the difference is mostly in the matter of ornamentation.

488. Joinery Work. The timber work described in Arts. 359 to 487 in this chapter has been chiefly what comes in ordinary classification under the head of Carpentry, the exceptions (such as finishing of eaves, skylights, lanterns, ventilators, barge boards, ornamental parts of verandahs and balconies and gates) being cases of work which, strictly speaking, belong to joinery, but which have been dealt with, on account of the advantage of describing together parts closely related. It is well nigh impossible to draw any distinct line of division between the two classes of work, because one trenches into the other to a great extent, and, as a matter of fact, they are both included in the one trade. As stated at the commencement of this chapter (see Art. 358), carpentry consists of the parts essential to stability, while the joinery embraces the more delicate, though not necessarily more skilful, work of making and fixing doors, windows, stairs, and such fittings. So far, this is perfectly correct, but in a detailed description of the two classes it is not so easy to distinctly classify. To illustrate the difficulty, take the case of a roof which is, as before stated, a work of carpentry, but the workmanship required to finish some of its parts, such, for instance, as barge boards or skylights, is often of a kind which may be rightly held to belong to joinery. To simplify the description such parts have been noticed as occasion demanded during the description of the carpentry work. Work, which according to the usual definition comes under the head of joinery is dealt with in the remainder of this chapter.

GENERAL IN REGARD TO JOINERY WORK

489. Finish of Joints in Joinery Work. In all kinds of timber work the parts of the joints should be made to fit with accuracy, so as to ensure strength; but in carpentry the joints need not be made with the extreme neatness of workmanship which is necessary, for the sake of appearance, in joinery. In the latter class of work the joints, which are intended to remain tight up, should be made so that the junctions are perceptible only by the difference of grain of the pieces joined.

490. Glue for Fastening Joints. Many of the joints in joinery work, not exposed to the weather, are fastened with glue; this substance is a gelatine obtained by boiling to a jelly the skins and hoofs of animals. The process of manufacture briefly described is as follows: The materials are first placed in

a lime pit, and after being well steeped are washed and placed on frames to dry, after which they are boiled down to the consistency of jelly. The jelly is then strained and allowed to stand for a time, so that impurities not removed by the straining may settle to the bottom. The clarified portion is then boiled a second time and further clarification is accomplished by settlement, and by the addition of chemicals. It is then run off into coolers about 6 ft. long, 1 ft. wide, and 2 ft. deep, in which it becomes a firm jelly. It is then cut up into square cakes, and sliced into thin pieces, which are placed on nets to dry. After some time the slices are removed to lofts, where the final degree of hardness is reached. The best kind of glue is hard and brittle, of a light amber colour and nearly transparent. When placed in water it swells considerably, but should not dissolve, and should return to its original size when re-dried. The method of preparing glue for use is as follows: The glue is broken up into small pieces and steeped, in as much water as will cover it, for about 12 hours. It is then melted in a proper glue-pot, care being taken that the outer vessel is filled with water so as to prevent the temperature in the inner one being raised above the boiling point of water, for, if the glue is burnt, it becomes useless. The glue should be applied as hot as possible to the timber, and a minimum amount only should be used, as an excess reduces the strength of the fastening. Considerable attention should be paid to quality and preparation of the glue used in such framed work as doors, sashes, panelling, etc., for upon the glue fastening depends the firmness of the joints. Glue may be made capable of resisting moisture, and, consequently, of use for joints exposed to the weather, or, to water, by putting a small quantity (about 1/50th of the quantity of glue) of bichromate of potash in the water which is used for preparing.

491. Finish of Surfaces. The exposed surfaces in joinery should be finished by being brought to a perfectly smooth state, and free from plane and other marks, by the use of glass paper. The latter is paper-faced with pulverised glass, and is supplied in different degrees of coarseness, ranging from No. 0, the finest, to No. 3, the coarsest.

492. Framing is the term which, in joinery, is more particularly applied to constructions composed of vertical pieces and horizontal cross pieces with intervening spaces filled with boards. The outside vertical pieces, or *"stiles,"* are always in one piece from bottom to top of frame, and are mortised to receive tenoned ends of cross pieces, or *"rails,"* and the boards or *"panels"* are secured by being let into grooves made in the stiles and rails. Vertical pieces, other than those of outside

edges of frame, are put in between and tenoned into the rails. Particularly dry timber must be used in framed work, but, even so, the scantling of the timber should not be too great, as the smaller the cross section of stiles and rails the less the liability to shrink and the better the work. The tenons are, for inside work, always secured with wedges and glue. The panels should fit fairly tight, but provision should be made for expansion and contraction, and they should not be fastened with nails or glue. Framing should always be put together loosely, and allowed to stand for some time before being permanently tightened and glued.

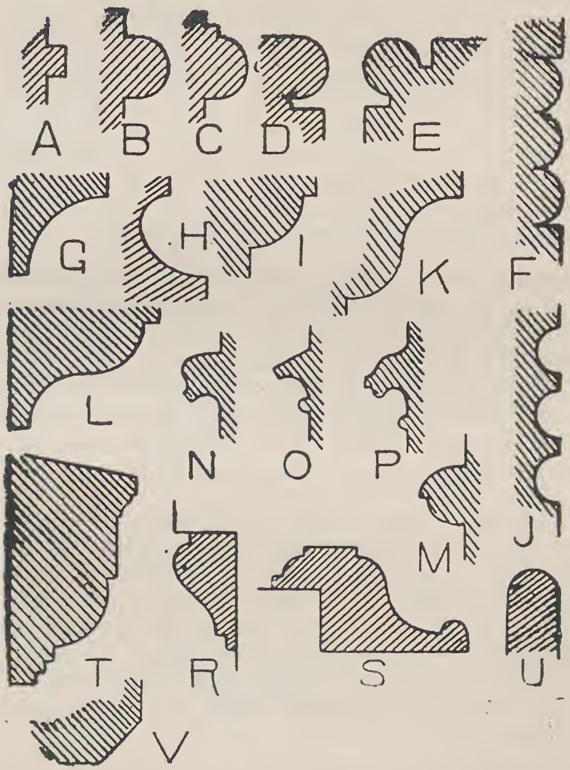


FIG. 93

493. Plugs. Pieces of joinery work, such as linings, skirting boards, architraves, etc., are fixed to walls by nailing to plugs, which are pieces of cedar or Baltic pine, slightly wedged shaped, about $\frac{3}{8}$ in. thick, and about 2 in. wide, driven tightly into the joints of the brickwork or masonry at distances apart

of not more than 18 in. An example of a plug is shown at P, in Fig. 96. In some cases slips of cedar, the thickness of the joints, are put in as the wall is built; this is done to avoid the chances of damage to the walling by the driving of the plugs. In superior work, grounds are fixed to serve as foundations for the linings, etc. *Grounds* are pieces of timber (usually Baltic pine) nailed to plugs and arranged so that their outer faces shall be flush with the finished face of the plaster. (See GL, sketch E, Fig. 94.) The edges next the plaster are bevelled so as to form a key for the latter. Sometimes a groove is formed in the edge for the same purpose. The pieces of timber for grounds are made the same thickness as the plaster work, and of a width to suit the requirements, which, it may be mentioned, rarely render necessary a greater width than 4 in. Where very wide grounds are required they are framed up out of pieces about 3 in. wide. Both plugs and grounds are put in before the commencement of, and serve as guides for the finish of, the plastering work. Consequently, the greatest care has to be taken that the heads of the plugs and the faces of the grounds come up to one vertical plane, and that the outer edges of the grounds are plumb.

494. Firring is the name given to the strips of wood put on to level up to a fair surface. An example of the use of this "firring," or "packing" is the case of the forming of a ceiling with lining boards. It often happens in a work of this kind that the edges of some of the joists, instead of being quite straight, are concave, and require to be packed up with strips of wood to the same plane as the straight ones, so that the surface of the ceiling shall be free from hollows.

495. Cradling. When a girder, for instance, is to be covered with a casing of boards, or panelling, or with fibrous plaster, rough framing consisting of pieces of timber 2 in. x 2 in. in cross section are built at intervals round its sides and bottom to carry the casing boards, or battens for fibrous plaster, as the case may be. This framework is called *"Cradling,"* which may be briefly defined as a supporting framework for casings of girders or columns, plaster work of heavy cornices, and ceiling, covers, etc.

496. Mouldings are continuous straight (or curved) lines of projecting (or recessed) plane and curved surfaces used for decorative purposes in building work. Each style of architecture has its own peculiar kinds of mouldings, and the design of these parts is a very important branch of architectural study, and a subject quite beyond the scope of this book. But, as the common forms of moulding are necessarily very

often referred to, especially in the articles relating to joinery, it is hardly possible to avoid giving a few particulars, consequently some cross sections or "profiles" of the principal members of the classic mouldings together with a few of Gothic and modern styles, are given in Fig. 93. So, to be as brief as possible, the names and other particulars are given in Table XXX. Timber mouldings are generally run by machinery, but require to be finished with hand planes, and should be well sand-papered so as to bring the edges perfectly straight and the surfaces smooth.

TABLE XXX

Giving names and particulars of mouldings shown in sketch, Fig. 93.

Distinguishing Letter in Sketch.	Name, etc.
A	FILLET: Generally used with other members.
B	ASTRAGAL: Usually called a *bead*.
C	TORUS: Composed of bead and fillet.
D	QUIRK BEAD: Used for edges of tongued and grooved boards, etc.
E	DOUBLE QUIRK BEAD: Called a *returned bead*. Used for corners.
F	REEDING: A number of beads together.
G	CAVETTO: As a rule this is called a *Scotia*.
H	SCOTIA: This is the proper form.
I	OVOLO, or quarter round.
J	FLUTING.
K	CYMA RECTA OR OGEE.
L	CYMA REVERSA, or reversed ogee.
M, N, O, P	FORMS OF GOTHIC MOULDINGS.
R	SUNK MOULDING FOR PANELS.
S	BOLECTION MOULDING, ALSO FOR PANELS.
T	MOULDING suitable for transoms, capping, etc.
U	NOSING: Used for edges of stair treads, window boards, etc.
V	CHAMFER: Much used for edges of all kinds of timber work.

DOOR OPENINGS

497. The subject of door openings can be most conveniently dealt with under the following heads, viz.:—

(*a*) Frames, and the finish round them.

(*b*) Doors.

498. (a) Frames are either *"solid,"* or what are called *"jamb linings."*

499. Solid Door Frames are used for external door openings, and are so called because the head and upright side pieces are of stout scantlings, and do not require stiffening support, that is to say, they are stiff enough in themselves to

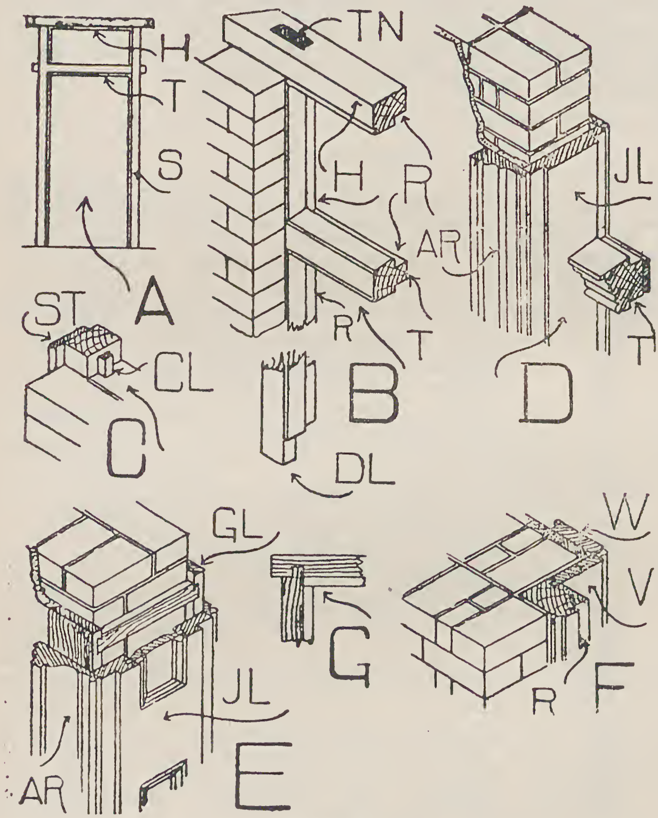


FIG. 94

form a frame which only requires support to keep in place. A front elevation of a solid frame is shown in sketch A, Fig. 94. The side pieces (S) are called "stiles," and the top piece (H) the head. In the frame shown provision is made for a fanlight or sash, over the door, the cross piece (T) separating the door from the fanlight being called a "transom."

500. The Sketches, B, C, and F, Fig. 94, give details connected with the construction and finish of solid door frames.

The stiles are tenoned into the heads (as shown at T N, sketch B, Fig. 94), and the joints are painted with white lead paint, wedged (as shown at H, Fig. 66), and well spiked. As shown by sketch B, Fig. 94, the ends of head pieces are allowed to extend for some distance past the stile so that the

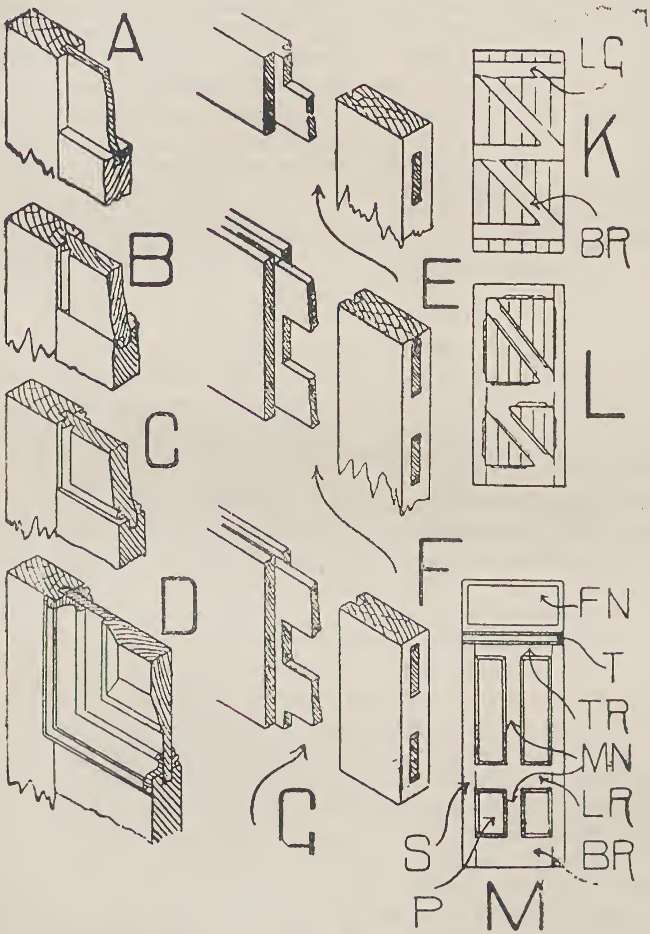


FIG. 95

wedging of the tenons may be done. These extended portions are called "horns." In cases where the door frames are flush with the inside surfaces of walls (see sketches B and C), the ends of the horns are cut on the bevel with a view to providing, on the principle of the dove-tail, a good hold in the wall. The feet of the stiles are finished with a tenon (as at D L, sketch

B, Fig. 94), which is let into a mortise cut in the door-step. An alternative method of fastening the feet of stiles into the step is to have a metal dowel passing from foot of stile into the step. (See dowel joint X, Fig. 66.) In the sketches B and F, Fig. 94, the rebates, R, R, R, into which the doors and fanlights fit, are cut out of the timber of stiles, heads, and transoms. When this is done the outer edge of the frame, which projects a little out from the masonry or brickwork reveal, is beaded, as at sketch B, or moulded, as at sketch F. In some cases, however, the rebate is formed by planting on a *"stop piece"* of pine about ½ in. thick, beaded on outer edge, and put so as to cover the joint of the frame and reveal, as at ST, sketch C, Fig. 94.

501. **Transoms.** As before remarked, a transom is a cross piece put in between head of door and bottom of fanlight, when the latter is to be provided. Transoms are either plain beaded (as at T, sketch B) or moulded on outer face, as at T, sketch D. As a rule, they are rebated for head of door, and bottom of fanlight, as shown in the sketches. Sometimes, however, the rebate for the fanlight is omitted, the top being simply bevelled upwards. Transoms should have their ends tenoned, and wedged into the stiles.

502. **Solid Frames are put in Position** when the doorsteps are set, and the masonry or brickwork is then built up round them. In cases where the frame is in the middle of the thickness of the wall (as at sketch F, Fig. 94), the building-in of the horns of the head, and the tenoning of the feet of the stiles into the steps provide for ample security. When, however, the frame is to be flush with the inside of the wall (as at B and C, Fig. 94), it is wise to provide some additional means to hold the frame in. The usual way is to nail two or three cleats, of 1 in. x 1 in. in cross section, and about 15 in. long, at intervals at the backs of the stiles. The bricks when being built up are cut so as to fit round the cleats. A portion of a cleat is shown at CL, sketch C, Fig. 94. Another very good method is to put bolts through the stiles, the heads being cut in flush with face of stile and the shanks extending out so as to be built into the wall. At least, two bolts should be put from each stile. It is necessary in every case to build a relieving arch (see Fig. 55) above the head of door frame so as to have as little weight on it as possible.

503. **Lining Boards in connection with solid Frames in External Walls.** When the door frame is put in, or near, the centre of a thick wall (as at F, Fig. 94), the space of the jamb from the inner side of frame to inner surface of wall requires

to be covered by what are called *linings*. These are pieces of board (V, sketch F, Fig. 94) planed up and secured by being tongued into the stiles and head of frame and nailed either to grounds or plugs.

504. Sizes of Solid Door Frames. For walls 9 in. thick, the width of the stiles should be from the reveals to the face of the plaster, which, allowing for $\frac{3}{4}$ in. of plaster, would be $5\frac{1}{4}$ in.; and the thickness (to suit the best bond for the brickwork, see Art. 150, *ante*, and Figs. 46, 47, and 50 on reveals and jambs), without the stop, should be equal to half a brick. Attention to the above considerations would give stiles $5\frac{1}{4}$ in. wide by 5 in. thick, with a rebate $\frac{1}{2}$ in. deep. As a rule, however, in ordinary work, the thickness is made 3 in., and the bond of the walling broken to suit it. The size of the head is generally made the same as that of the stiles. In large openings the sizes are made considerably greater than given above.

505. External Door Frames are sometimes made with curved heads, the form of the curve being either semi-circular, segmental, semi-elliptical or Gothic, as the style of architecture may be. In cases of this kind the head is cut out of solid timber in two or more pieces, according to the size of the opening, and these pieces are joined together either by tenoning and pinning, or by means of the end but and keyed or bolted joints (as described in Arts. 373 and 374, *ante*.) The whole head so formed is fastened to the stiles in the same way that the pieces are jointed, or by halving and screwing. Sometimes a style of construction is adopted for external openings, by which means the outside shows curved while the inside remains square-headed. The sketch A, Fig. 96, shows a corner of a frame of this kind. It will be seen that the frame is made with a straight headpiece (H), just as in the ordinary frame, the curves being formed by solid pieces which are of a thickness to extend from rebate to outer edge of frame. These pieces are arranged so as to meet at the centre of the headpiece, and are housed into the latter and into the stiles. As will be seen by the sketch, the curve springs from flush with face of stile, and extends to flush with centre of head. The arch marked A R in the sketch is built flush with, and following, the curve formed by these pieces. It is the general practice to extend a planted pine stop, S T (bent as required by steaming), round the soffit formed by these pieces, as shown by the sketch. But sometimes the pieces are made to project the required distance, and are carefully planed up, and beaded on outer edges, so as to be the continuation of a stop worked in the solid on the stiles. The doors or fanlights for such frames would be made with the heads actually square to fit the rebate,

but the heads of the panels (on the outside at least) would be made to suit the curve (see R, Fig. 96, which is a sketch of one leaf of a door for such a frame), while fanlights would be made with the opening for the glass also to suit the curve.

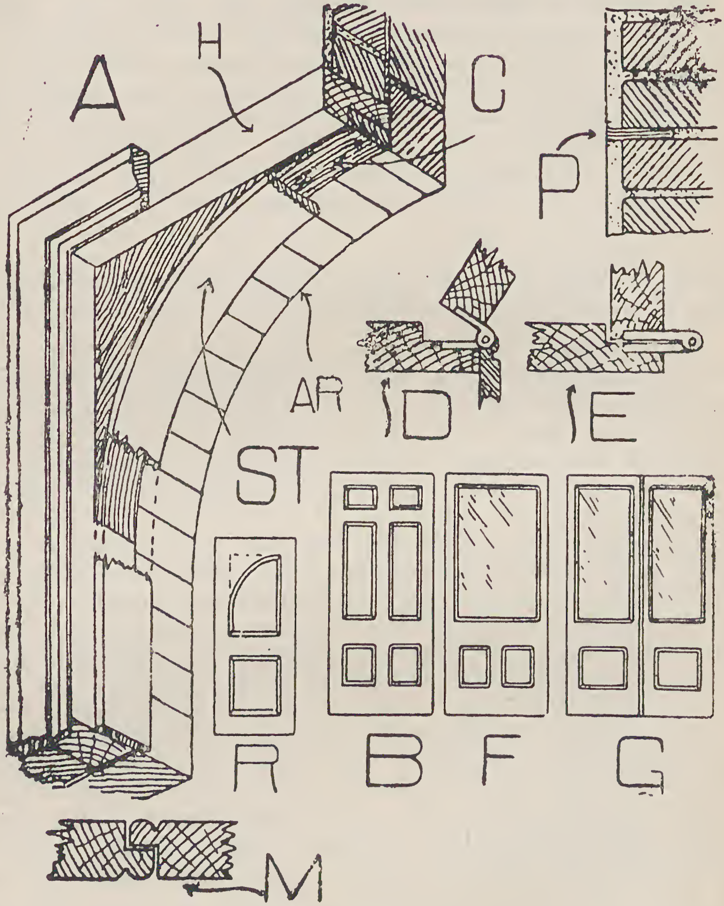


FIG. 96

506. Timber for Door Frames. The following are some timbers useful for this purpose:—

(a) HARDWOODS: *Tallow wood,* Red Mahogany, Grey Gum, *Jarrah,* Forrest Red Gum.

(b) TIMBERS OF THE SOFT AND FIGURED CLASS: Cedar, *Colonial Beech,* Rosewood.

(c) PINE TIMBERS: Oregon Pine, Colonial Pine.

(Those in italics are especially suitable.)

507. Jamb Linings. The timber linings used to finish the jambs and soffit of a door opening in an internal wall, and to hang the doors to, are called jamb linings. This name is indiscriminately given to all linings and jambs of windows, and also to inner jambs of external doors (as at V, sketch F, Fig. 94.) The linings of internal doors are, however, generally known specially as *jamb linings*, the others as *linings*. A portion of an ordinary jamb lining for an internal door opening in a 4½ in. or 9 in. wall is shown at JL, sketch D, Fig. 94. The upright pieces are called *jambs*, while the cross piece or head is known as the *soffit*. The thickness usually adopted for jamb linings of this kind is 1½ in. and, as will be seen by the sketch, they are made just wide enough to have the outer edges flush with surfaces of plaster on each side of the wall. Though a rebate for the door to fit into is only needed on the edges of one side, it is usual to put a rebate, for the sake of appearance for walls thicker than 4½ in., on the other edges as well. The sketch D shows a *double* rebate jamb. The jambs are tongued into the head as shown by small sketch G, Fig. 94; and the whole frame or lining is secured in place, before the plastering is done, by nailing the jambs to cedar plugs, and the soffit to the wood lintels under the relieving arch at the head. In the sketch D, Fig. 94, the portion of a transom at its junction with the jambs is shown. The transom would be secured by tenons into the jambs. In the case shown by D, Fig. 94, the preparation of the rebating above the transom would be for a fanlight to hang with hinges at bottom or top. If the fanlight is to hang on pivots the portions of jambs above transom must not be rebated, or the rebate, if made, must on each side be filled up with a lath. The necessity for this will be obvious, for if the fanlight is to swing on its centre it must be made of the width between the thickest part of the jambs, *not* of the greater width between the rebates. For the same reason either the rebate at head of frame, or that at top of transom, must be omitted.

508. When the openings are in walls of greater thickness than 9 in., the jamb linings should be composed of framing, as linings of great width are apt to warp and split. A portion of framed jamb lining is shown at JL, sketch E, Fig. 94. Each jamb and soffit would be framed up with stiles, rails, and panels, as shown by the portion in the sketch, the height of panels and the mouldings being the same as in the door. Framed jamb linings are almost always double-rebated. In superior work the jamb linings are not fixed until after the plastering has been completed, but the grounds (GL, sketch E, Fig. 94), which are also to provide a precise foundation and

a good fixing for the jamb linings, are put up before the plasterer commences, so as to give him a guide for his work.

509. It may be mentioned that the external doors in stud walls (see Art. 465, *ante*) are generally hung in jamb linings. A method of forming an external door opening in stud walling is shown at sketch C, Fig. 90, in which is the section of the head, K being the soffit of the lining.

510. The following timbers may be used for jamb linings: First Class, or Polished, or Varnished Work.—Cedar, blackwood, rosewood, Queensland maple, Pacific maple, silky oak, red bean, colonial beech, onion wood, and others of those mentioned in Arts. 305 to 324, *ante*.

Ordinary or Painted Work.—Baltic, kauri, oregon, or colonial pine.

In cases where the joinery work is to be painted, the jamb linings are generally made out of either kauri, oregon, or colonial pine.

511. Finish Round Door Openings. In public buildings, and houses of superior construction and finish, the door openings are often finished in a very elaborate manner. Pediments or *over-doors*, supported on pilasters or columns of elaborate design, are used to embellish the openings, and every advantage is taken of the opportunity to make a feature in the internal effect.

512. The usual method of finish is to put pieces of timber mouldings up the sides and over the head of the opening. These mouldings (called architraves) are nailed to edges of jamb linings, and to wood plugs or grounds, and cover the joint between plaster and jamb lining, as shown at AR, in sketches D and E, Fig. 94. Sometimes, however, the architraves are simply pieces of board about 1 in. thick, with top-chamfered or beaded edges, an example of the latter being shown at W, sketch F, Fig. 94. Moulded architraves are mitred at upper corners, but those with top-chamfered edges are generally overlapped and halved at top angles, after the style of an Oxford picture frame.

513. In cases where the skirting is thicker than the architraves a block (as shown at BL, Fig. 97) must be put to form a stop. The blocks are, however, sometimes adopted for sake of appearance, where not really necessary. In any case, their use may be recommended, for, if carried down to the floor, the mouldings of the architraves are likely to be damaged during sweeping operations. Architraves are made upwards from

about 3 in. wide by 1 in. thick, but in ordinary work they rarely exceed 6 in. wide by 1½ in. thick. When the architrave is so formed as to have one large plane surface back from another (as shown at AR, Fig. 97), it is called *double-faced.* In such cases the thickness of the architrave varies very much,

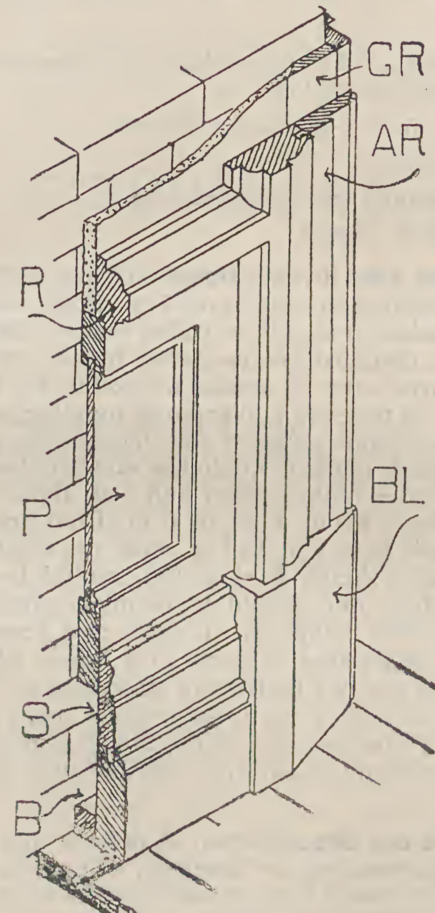


Fig. 97

and in order to avoid the labour of sinking in the solid, and also to gain the advantage of having small pieces of timber instead of one large piece, it is made in two pieces, which are joined together with tongue and groove, and glued. A double-faced architrave built up with two pieces of timber is shown at AR, Fig. 97. Architraves should on no account be fixed

until after the plastering is finished. The timber for architraves may be, in cases where the work is to be painted, either redwood, baltic, or oregon, or colonial pine, the former being the best to use. In polished or varnished work the timber for the architraves is made to match the jamb linings. (See Art. 510, *ante*.)

514. (b) Doors. The various kinds of doors may be classed under four heads as follows:—

(1) Ledged and Braced Doors.

(2) Framed „ „

(3) Framed and Panelled Doors.

(4) Flush Doors.

515. Ledged and Braced Doors. Doors of this kind are made with boards 6 in. wide and 1 in. thick, arranged vertically and nailed to cross pieces called ledges, the whole being stiffened with diagonal pieces called braces. A sketch of a ledge and braced door is shown at sketch K, Fig. 95. The boards should be tongued and grooved together, and the joints ornamented (on both sides of the door) with a bead or V. The ledges (one is marked LG in the sketch) should be placed at the middle and both bottom and top, those at the latter places being kept about 4 in. to 6 in. from ends of boards. Ledges are made from 6 in. to 8 in. wide and about 1¼ in. thick. The braces, BR (sketch K, Fig. 95), should be of the same size as the ledges, and should be inclined upwards from the edge that the door hangs at. Ledged and braced doors are only used for outhouses or parts of a house where strength and appearance are not matters of importance. When a door is made without braces (as is sometimes done) it is called a "ledged" door. The omission of the braces is not to be recommended, for without them the door is sure to get out of square.

516. Framed and Braced Door. A door of this kind consists of a frame and a covering, or "sheeting," of boards. (See Sketch L, Fig. 95.) The frame is composed of stiles and rails mortised and tenoned together and stiffened with braces. The boards are tongued and grooved together, and the joints either beaded or V cut, and when in position the external faces of the boards are flush with faces of stiles and top rail. This means that the bottom and middle rails and braces are to be so much less in thickness than the stiles and top rail. It will, consequently, be clear that doors of this kind cannot very well be made less in thickness than 2 in., which gives 1 in. for boards, and 1 in. for middle and bottom rails and braces. The rails should,

however, if possible, be not less than 1¼ in. in thickness; so that a good door would be 2¼ in. thick at least. The edges of stiles and top rail should be rebated to receive the boards, and the edges nearest the boards should be beaded, while the edges of stiles, rails, and braces, on the inner side, will look well if stop-chamfered. The braces of this kind of door are not altogether indispensable, though they make a much stronger door. Framed and braced doors are strong and well fitted for almost any position where strength is necessary, and where a plain appearance is not objectionable. Church doors are made somewhat like the door just described, the main difference being the curved top part and the omission (as a rule) of the braces, and the boards are usually placed diagonally instead of vertically.

517. Framed and Braced Doors are used only for external openings, for which position they are certainly more suited than the framed and panelled doors. Sometimes, however, as in churches, the framed and braced door is used for both external and internal openings.

518. Framed and Panelled Doors. A door of this kind (a four-panelled one) is shown by sketch M, Fig. 95. As will be seen, it is composed of stiles (S), bottom rail (BR), middle or "lock rail" (LR), top rail (TR), muntings (MN), and panels (P). A fanlight (FN), and transom (T) are also shown in the sketch, but the present description does not deal with them. Sketches E, F, and G, Fig. 95, show to a large scale the methods of tenoning rails into the stiles and the grooving for the panels. E shows top rail tenon with a haunch on upper part, to leave some timber of the stile at the head. F shows the middle rail with the tenons and an intervening haunch. The mortise lock is sometimes put in the stile so that it will come between these tenons and thus avoid damage to the joint, which would result if the tenons were cut away. G is the bottom rail, which has two tenons and a small haunch at lower part of bottom one, put on for the same reason as given for that on top rail. The thickness of the tenons is made about one-third that of stiles, and all are secured with glue and wedges. The muntings are put in between and stub-tenoned into the rails. The inner edges of stiles, bottom and top rails, and both edges of lock rail and muntings, are "ploughed" or grooved about ½ in. deep for the panels; these grooves are shown in the sketches. Though the form of door shown at M, Fig. 95, is the most common, the number of the panels is by no means confined to four. For instance, the bottom munting may be left out, in which case the door would have three panels. Again, a *frieze* rail is put in below the top rail (as

shown at B, Fig. 96), and forms six panels; and so on, according to the taste of the designer. It is well, however, when designing the door to take care to avoid large panels, for the latter are liable to crack and split. The method of finishing the panels determines, in conjunction with the number of them, the name of the door, as for instance, *"Four Panelled, Bead Flush, and Square Door,"* is the description of a four-panelled door with the panels, finished in a certain way. The principal methods of finishing panels in framed work or doors are as follows:—

519. Square and Flat Panels. This is the name given to the panels when less in thickness than the framing, and finished as let into the frame without any mouldings. (See sketch A, Fig. 95.) Sometimes the edges of the frame are ornamented with a stop-chamfer, in which case the finish might be called—*"Square and flat panels with stop-chamfers."*

520. Moulded and Flat Panels. Where the panel described above is finished with small mouldings put in, or *"planted,"* round the panel and up against the frame, the finish is called *moulded and flat.* The finish may be on one or both faces of the panel. The moulding may be sunk or planted after the style of that shown at R, or the protruding kind known as bolection moulding (S, Fig. 93.)

521. Bead Butt Panels. (See Sketch B, Fig. 95.) In this case the face of the panel is flush with the face of the frame, the edges adjacent to the stiles being beaded, while those against the rails are closely butted. The portion of panels let into the groove in the frame, forms, in this style, a tongue. The bead butt finish may be on one or both faces of panel. When on both faces the panel will be of the same thickness as the frame. As a rule, however, this finish is put on one face only, the other being square and flat, or square and moulded.

522. Bead Flush Panels. This kind of finish is much like that above, the difference being that the bead is carried all round the edge of the panel. (See Sketch C, Fig. 95.) What was said about bead butt, on one or both faces, applies equally to this kind.

523. Raised and Moulded Panels. This kind of panel is thicker in the middle than round the edges, the part round near the framing being flat and the centre being raised in the form of a "full" or "truncated" pyramid. The moulding is generally the kind known as "bolection." A corner of a raised

and moulded panel is shown at D, Fig. 95. The panel may be raised on one or both faces of the panel. As a rule, however, the raising is on one face only, the back left flat and sunk moulded, as shown in the sketch.

524. Panels should not be fixed with either nails or glue, but should be left so that movement due to shrinkage or swelling may take place freely, and without causing cracks. For the same reason the planted or bolection mouldings should not be nailed to them, but to the framing.

525. Doors made in Leaves. If the width of the opening is 3 ft. 6 in., or more, the door should be made in two pieces or "leaves," as they are called. This is necessary, because if more than about 3 ft. in width the tenons in the hangings stile are stressed too heavily and are apt to give. Each leaf is the same as a single door, in construction and general appearance, except that in most cases the muntings are left out, thus providing for the same number of panels as if the door were made in one piece. The edges of the leaves where they meet in the centre are rebated and beaded (as shown at M, Fig. 96). In cases of very wide door openings, such as those which are used to form two rooms into one as occasion requires, the doors are made in four, or even more, leaves. The leaves are divided into two sets—those in each set being hung to each other—the outermost in each being hung to the jambs. The width of each leaf in the case of folding doors should not exceed 2 ft. The edges of leaves, where hung to each other, and where meeting at the centre, should be rebated, and beaded (as at M, Fig. 96.) The leaves should be so arranged and hung that they fold back on each other when opened back. Doors made in a number of leaves are never a great success, for the leaves furthest from the jambs have a tendency to drop or "sag." To get over the difficulty with wide openings, a better way is to have the whole door made in two leaves only, each being suspended by straps to flanged wheels which run on overhead rails or bars, the opening of the door being performed by pushing the doors on the wheels into cavities in the wall on each side.

526. Sash Doors. Doors made with upper part in one space, and the latter filled with glass, are called "sash doors." (See F, Fig. 96.) It is usual in these doors to make the width of the upper part of stiles less than the lower part, the difference in width in each stile being made in the part between the top and bottom of the lock rail by having the shoulders of the latter slanting instead of square. The stiles in such cases are called "diminished stiles." The upper edges of the stiles, and

that of the top rail, are either rebated for the glass and moulded like a sash (see Art. on Sashes), or provision for fixing the glass by beaded fillets is made; the latter is by far the better way. Sometimes sash bars are put in so as to divide the upper space into a number of parts, a favourite style of division being to put a bar about 4 in. in from the edge of stiles and rails right round, thus forming a margin round a centre pane. The margin is divided by cross bars at intervals. A door of this kind is called a *"margin light"* door. A kind of door called a *casement* is shown at G, Fig. 96. This is very much used for openings in external walls leading on to verandahs. As will be seen by the sketch, it is really a sash door made in two leaves, each having upper spaces of glass and diminished stiles. In the sketch the lock rails are shown at the same height as in other doors, but, in many cases they are put very much lower. It is, however, very unwise to put them any lower than the top 2 ft. 6 in. from the floor. Casements and sash doors, if put in external openings, may have outer faces of lower panels raised and moulded and inner faces flat and moulded. Casement doors should never be put in external openings unprotected by verandahs or covered balconies, and even then should have the protection of shutters. It is a general custom to put wood sills (like those for sashes) fitted with water bars at the feet of these doors, but, if the doors open inwards, the bar is not of much value, and, consequently, the sill is next to useless.

Casement doors are available without a wood lower panel and divided into a number of glass panels by sash bars, the whole space between the stiles, top and bottom rails being taken up by the glass.

All glass doors glazed with bevelled plate glass are often used as swing doors to city buildings. Such doors have no sash bars, the space between the stiles, top and bottom rails being plate glass.

526a. Flush Doors can be either a solid core built up of laminations glued together on fairly large pieces of timber, the full thickness glued together covered on both surfaces with thin veneers, or a framed door covered on both surfaces with thin veneers.

527. Sizes of Doors and their Parts. Doors or openings for the passage of people should never be made less in width than 2 ft. 6 in., or less in height than 6 ft. 6 in., while the thickness should not for the sake of good construction be less than 1½ in. in any kind of framed doors. The corresponding

sizes of width, height and thickness in ordinary doors are as follows:—

Width.	Height.	Thickness.
2 ft. 6 in.	6 ft. 6 in.	$1\frac{1}{2}$ in.
2 ft. 8 in.	6 ft. 8 in.	$1\frac{3}{4}$ in.
2 ft. 10 in.	6 ft. 10 in.	$1\frac{3}{4}$ in.
3 ft. 0 in.	7 ft. 0 in.	2 in.
3 ft. 6 in.	7 ft. 0 in.	2 in.
4 ft. 0 in.	8 ft. 0 in.	$2\frac{1}{4}$ in.

The parts of ordinary doors are made of the following sizes:—

Stiles	$4\frac{1}{2}$ inches wide	
Muntings	,, ,, ,,	All being of the same thickness.
Top Rail	,, ,, ,,	
Lock Rail	9 ,, ,,	
Bottom Rail	,, ,, ,,	

528. Panels should never be less than $\frac{3}{8}$ in., but generally are $\frac{1}{2}$ in. thick. The upper part of stiles and top rail in sash and casement doors are from $2\frac{1}{4}$ in. to 3 in. wide. The top of the lock or middle rail is, in ordinary practice, put at from 3 ft. to 3 ft. 3 in. from the bottom of the door.

529. Timber for Doors. The following are some timbers which are suitable for this purpose:—

Ledged and Braced and Framed and Braced Doors.	Baltic Pine, Oregon Pine. Redwood or Colonial Pine.

Framed and Panelled Doors:—

Painted Work.—Oregon Pine, Baltic Pine, Redwood, Clear Pine, Sugar Pine, Kauri Pine and Colonial Pine.

Polished or Varnished Work.—Queensland Maple, Blackwood, Cedar, Rosewood, Colonial Beech, Kauri.

530. Gluing and Wedging up a Door. The stiles, rails and panels should be loosely framed together, and allowed to stand for a time before being permanently tightened up and fastened. The latter work is done on the bench as follows: The door as loosely framed is put resting on bearers, which are "out of wind," that is to say, the upper edges of all are in the one plane. The tenons are exposed and painted, as well as the mortises, with the glue. The whole is then knocked together with hammers, and finally tightened with "cramps"; wedges, also painted with glue, are then driven in at edges of the tenons. Great care should be taken to drive the wedges on each edge as equally as possible to prevent breakage of tenons. The cramps are next removed, and the whole of each side of door planed to a fair surface and glass papered until quite

smooth. Mouldings (if there are to be such) are then cut into the panels and "bradded," that is, nailed with thin nails or "brads" to the stiles and rails. The ends of the stiles longer than necessary are not cut off until when hanging the door.

531. Hanging of Doors. The operation of fitting a door into the frame or jamb lining and fitting and putting it on to hinges is called "hanging." The fitting in the rebate of frame or jamb lining should be done with as much accuracy as possible, and it goes without saying that the better the door and frame the better the finish should be. In the case of the ledged and braced door the amount of space between the rebate and edge of door would not be so small as is the case of a good-framed and panelled door for an internal opening. In any case, however, the smallest possible space compatible with easy opening and shutting should be arranged for. In the best kind of work the space is very little, indeed there is, practically speaking, hardly any at all. In ordinary work the space is about what the edge of a two shilling piece would fit in. In ledged and braced doors it is oftener about $\frac{1}{4}$ in. than otherwise. The foregoing refers to the joint at the side and top; the joint at the foot is, of course, necessarily bigger, for even in superior work the doors have to open back over thick carpets, etc., and allowance must be made accordingly. But no more than is absolutely necessary should be allowed, for a big space under a door induces most uncomfortable draughts. To fit and hang a door with the minimum amount of joint space is only possible when the door is made of seasoned timber not liable to shrink or swell. Many of the machine-made doors in use are made of poor pine which shrinks and swells with change of weather, and as a result a door is tight, so as to stick, one week, and the next is so loose as to appear very bad. Ledged and braced doors are hinged on T hinges. The framed and braced are also at times hung on these hinges, but when strength is required the hinges are either those shown at F, Fig. 92, or what are called *butt hinges.* Framed and panelled doors are always hung on *butt hinges.* An example of the latter kind is shown at D, Fig. 96. As will be seen, they fit into the edge of the door and in the rebate of the frame or lining. They range from $1\frac{1}{4}$ in. to 6 in. in length, and are made in brass or steel in many finishes. The round part, where the centre of revolution is, is called "knuckle." In ordinary work two of these butts are used (in good work, three) to hang a door from 6 ft. 6in. to 7 ft. high, the positions being one at level of top of bottom rail, one at level of bottom of top rail, and the third (if such there be) central between the other two. The usual way is as shown, to sink the hinge the depth of the thickness into

edge of door, and into rebate of frame or jamb lining. When the door is required to open back, and clear a projection, such as a thick architrave, the knuckle must be put well out (as at E, Fig. 96). Each flap of the butt is secured with 3 or 4 screws into edge of door and rebate. Doors should always be hung inwards to a room, and should be hung on the edge that will allow of its covering the most of the room when partly open. Doors of public buildings and churches, etc., are exceptions to the rule of opening inwards, for owing to the danger of panic, they should open outwards, to prevent any chance of their becoming fast from a pressure inside, as would very likely occur if hung to open inwards.

Swing doors are hung with double action spring hinges, sufficient space being left at the meeting stiles to allow of the doors opening both ways.

Doors may be made to slide and are usually hung on special steel tracks.

532. Fanlights. These are sashes put over doors to give extra light, and also to provide means of ventilation. They are made much in the same way as sashes (see Articles on Sashes), with stiles and top rails from 2¼ in. to 3 in. wide, and bottom rails a little wider, the thickness being the same as the door. They are sometimes fixed tight in place, but as a general rule they are made to open and shut to give ventilation. When made to open and shut they are hung either with butt hinges on the bottom edge, or on pivots at about the centre of the stiles. In the former case they are made to fit into the rebates above transom; but when pivots are used the rebates are filled up, or else not made at all in the upper part of the sides of door frame or jambs, and the fanlight is made of the width between the top faces of jambs or frame, so that in opening either the upper or lower part (as may be arranged) shall be able to swing in between. It is also necessary to note that, when the fanlight is hung on pivots the transom is made without a rebate on top, so that the bottom part of fanlight may be able to swing clear in an outward direction. Pivots consist of what may be called bolts and sockets. The bolt is a pin about ½ in. diameter fastened to a plate, which is secured with screws to the sides of sash. The pin or bolt works, or revolves, in a hole in a socket plate which is secured to the jambs or side of frame. The socket plates are made with a slot the same width as the diameter; these slots lead down to the holes in which the pins work; consequently, the sash or fanlight may be removed bodily, if required, by lifting it so that the pins come up by way of the slots. Pivot hung is the best way for fanlights over internal doors.

WINDOW OPENINGS

533. The Joinery Work connected with window openings consists of the following:—

(1) Frames.
(2) Sashes.
(3) Finishing Round Frames.

534. Window Frames. These are either—

(a) Boxed.
or (b) Solid.

535. Boxed Window Frames. Such windows as indicated in Fig. 98 are constructed of sashes which slide up and down. The sashes are counterbalanced with balance weights in the boxes and connected to them by sash cords over pulleys, which allow of the sashes being moved up and down or held in any open position. A frame of this kind may be said to consist of sill, side casings, and head. The sill is made of hardwood, and is from 3 in. to 4 in. at the thickest part, and of the width of the side casings. Cross sections of sills for box frames are shown at R, Fig. 60, and WS, Fig. 98. A better view is given at A, Fig. 87, which shows a sill finished much in the same way on the top surfaces as one for a box frame. It will be seen by the sketches that the top of the sill is formed with a level portion about one inch wide as inner edge, and the rest in two or three stepped slopes. The step, or portion forming the rise between the slopes, should be hollowed out or "throated." The slopes are called "weatherings." The object of the weathering and the throating is to get the rain-water away as quickly as possible, and to prevent it from getting in under the sash. To fully accomplish this it is necessary to work the sill (as shown in the sketches, Figs. 98 and 99) with three slopes, two of the latter and a stepped throat being under the sash. In unimportant work the sill is made with only two slopes (as at R, Fig. 60). The side and head casings are much alike. A cross section of a side is shown by sketch C, Fig. 98, while the section of a head is depicted in the large sketch, Fig. 98. The parts of the casings are as follows:—

536. Pulley Stiles. These are the pieces of timber (P.S.T. sketches BC, and D, Fig. 98), against which the edges of the sashes abut and slide. They also contain the pulleys (PY) sketch B, over which the hanging cord passes, and are grooved to receive the parting bead (PB, sketch C, Fig. 98). The lower ends of the pulley stiles are housed and wedged into the hardwood sill (as shown at sketch E, Fig. 99). The *head*

(H, Fig. 98) of the box frame is of the same cross section as the pulley stiles, and grooved and otherwise prepared much the same, excepting that there are no pulleys or pockets. Pulley stiles and heads are made as a rule $1\frac{1}{4}$ in. thick.

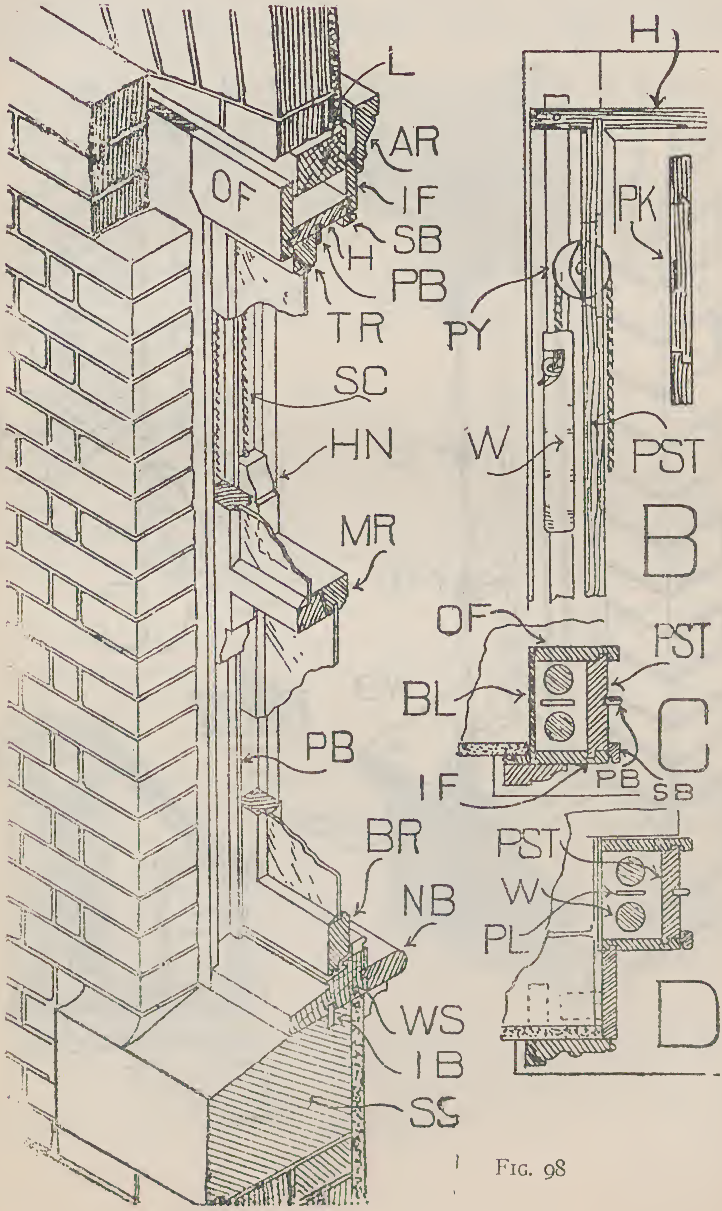


FIG. 98

537. Inner and Outer Facings. These are pieces of timber put on to form the backs and fronts of the casings. These pieces are frequently called linings, but, to distinguish them from the linings used for internal finishing, it is best to call them *facings*. The outer facings (OF, Fig. 98) are made wide enough to project about $\frac{5}{8}$ in. to $\frac{3}{4}$ in. in front of the face of the pulley stiles, to form a guard to keep the top sash in place.

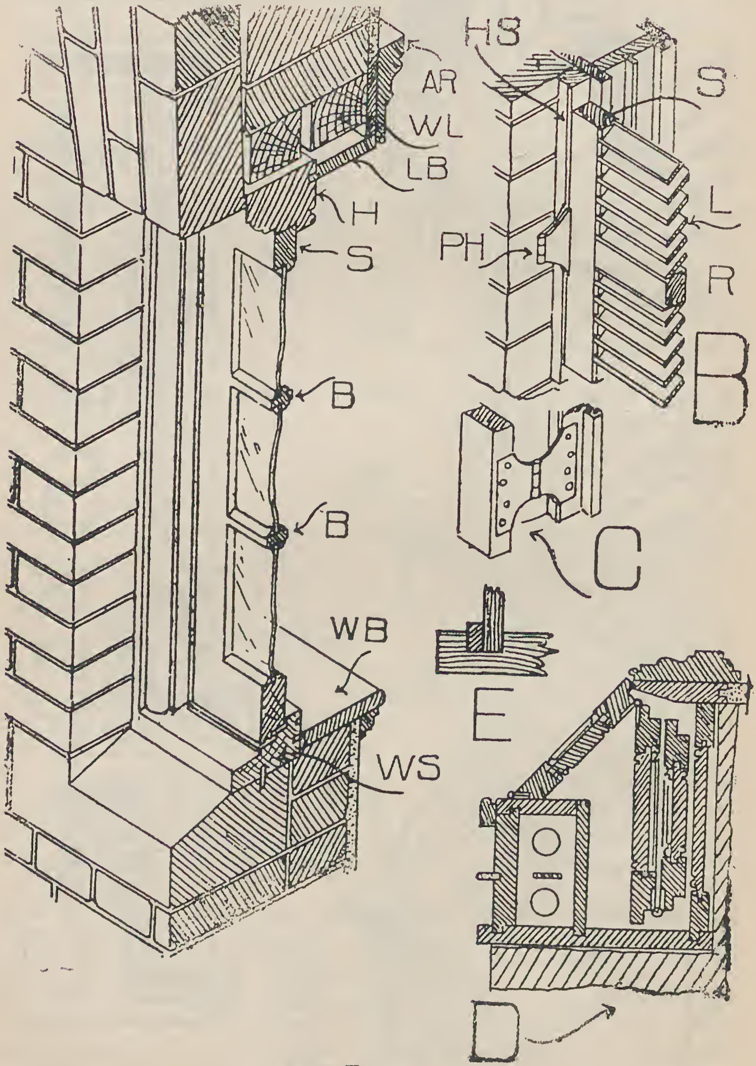


FIG. 99

The inner facings are, however, not so wide, the edges being kept flush with the faces of pulley stiles. The thickness of the facings varies from $\frac{5}{8}$ in. to 1 in., according to the class of work. In common construction the facings are only nailed to the pulley stiles, but, for good work, the joint should be made with tongue and groove, as shown in the sketches. The facings are put to the head of the frame just as to the pulley stiles. (See sketches.)

538. Back Linings. These are the pieces of timber put at backs of side casings to keep mortar, etc., from getting in. A back lining is shown in sectional plan at BL, sketch C, Fig. 98.

539. Stop and Parting Beads. These are the strips, beaded on outer edges which are used to keep the sashes in place. The parting beads (PB, Fig. 98) are let into grooves in the pulley stiles and head and so placed to keep the sashes apart. The stop beads (SB, Fig. 98) are nailed to edges of casings, head and sill on the inner edge of the frame, to keep the inner or bottom sash in place.

540. Solid Window Frames. The large sketch (Fig. 99) is a vertical section of a window opening with a solid frame. Such a window as indicated in Fig. 99 is constructed of a sash which is hinged on one side to open usually outwards and is referred to as a casement. WS is the sill, which, it will be noted, is made like one for a box frame. H is a cross section of the head, and the stiles would be of similar shape. The stiles would be housed and tenoned into the sill and tenoned into the head. As will be seen, the stiles and head are rebated to receive the sash, which, in the case illustrated, is arranged to open outwards, this being the best way. If the sash is to open inwards, the rebate must be put on the inside, and the sill shaped a little differently, to guard against the inroad of the rain-water. In the example given the outer edges of the stiles and head are moulded, but, as a rule, the edges are mostly beaded, as in the case of a door frame, as shown in cross section of stile at B, Fig. 94. It will be observed that a solid window frame is made much like an external door frame. The frame in Fig. 99 is for sash hung at side (if in one leaf, or at sides if in two), with butt hinges. In the case of the sash being hung on pivots, as is sometimes done, the rebate would be formed with stops (as described in Article 532, *ante*).

541. Timbers for window Frames. The timbers set out in Art. 506, *ante*, for door frames may be taken as also suitable for solid window frames. As before remarked, the sills of the boxed frames should be of hardwood, if possible. The other

parts may be of the same kinds as set out in Art. 510, *ante*, for jamb linings, but redwood may be added to the list.

542. Fixing of Window Frames. Solid frames are almost always set in during the building of the wall, and fastened in the same way as described for a door frame. Boxed frames, in ordinary building, are also built in the walling, but in superior work they are put in after the walls and roof have been completed. It will be obvious that the latter way is the best, because the frame escapes the damage, which is inevitable, if put in when the masonry or brickwork is being done. When built in, the ends of the sills are bevelled like the head of a door frame, to improve the hold in the wall. Wood lintels (L, Fig. 98, and WL, Fig. 99) should in all cases be put over the frames, to carry the overhead brickwork, but in no case should the lintel be allowed to bear on head of frame. The sketches, Figs. 98 and 99, show relative positions of the lintels. It is better construction to use a wrought iron arch bar to support the brickwork instead of a wood lintel. A water bar of galvanised iron or copper should be put to project into both brick or stone and wood sills, and form a barrier to the passage of water. The wood sill is generally bedded on to the stone sill in a thin layer of cement mortar.

542a. Storm Mould. Such is a mould usually an ovolo as at I, Fig. 93, or a cavetto as at G, Fig. 93, about 1 in. size, and is fixed to the external face of a door or window frame to cover the joint between same and the wall surface.

543. Window Sashes. A sash is a light frame containing the glass, and fitted to hang or slide in the "solid" or "boxed" window frame. The construction of sashes depends upon the following:—

(a) Sashes for Boxed Frames.

(b) Sashes for Solid Frames.

544. Sashes for Boxed Window Frames. For boxed frames the sashes are made in two pieces, known, respectively, as top and bottom sashes, and hung with cords and counter weights, to slide up and down. Portions of a sash for a box frame are shown in position in the large sketch, Fig. 98. The stiles of each sash and the top rail of the top one are alike in width, while the bottom rail of the bottom sash is wider, and the connecting rails narrower than them. As shown by the sketches, the stiles in each sash are extended past the meeting rail and finished with a moulding, such extensions being called "moulded horns." The horns give finish to the stiles and also provide for stability in the joint with the meeting rails. The

latter are generally bevelled at the meeting surfaces as shown in the sketch, but in superior work the junction is made with a bevelled rebate. It will be noticed that the sashes are kept apart by the thickness of the parting beads (PB), but the meeting rails are wider by the amount of the bevel, to fill up the space at this junction. The under edge of bottom rail of lower sash is rebated and bevelled and grooved, as shown in Fig. 98, or simply bevelled as the importance of the work may demand. The best way is as shown in Fig. 98.

545. The glass is secured with putty in a rebate, excepting in the case of the meeting rail of bottom sash, which has a groove, to take the glass, formed in the outer edges of the frames, while the inner edges are moulded. The sketch, Fig. 100, shows a top corner of a top sash just as it is being put together. RL is the rail with tenon and haunch, and the

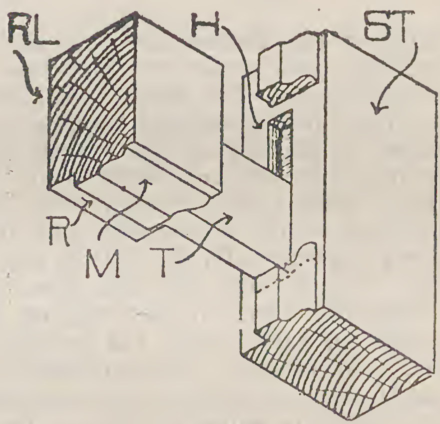


FIG. 100

moulding scribed already to fit into and against the stile ST. The other joints are made similarly—a slight difference only in the case of the meeting rails—the haunching (if done as shown in Fig. 98) not being necessary. It may be remarked that the sashes are made so that when together (as in the drawing) the meeting rails are in the centre of the height between the top of bottom rail and bottom of top rail. In the example illustrated (Fig. 98) each sash has only one pane of glass. Sashes are not, however, always so made, for it is often the case that each has two or more panes. The divisions are formed by narrow pieces, each rebated and moulded like the stiles and rails, and called *sash bars.* (See B, in large sketch, Fig. 99). The bars are arranged horizontally and vertically, as the division may be (if there are bars both ways, one would

run right through, while the others are formed of pieces put in between), and the joints with sashes and with each other are made with tenons and scribed intersections, as in the case of the stiles and rails. The bars are frail, and, in the case of a sash with a large number of divisions, a considerable amount of skill is required to get all equal and all perfectly straight. Sashes are generally made from $1\frac{1}{2}$ in. to $1\frac{3}{4}$ in. thick, but in large windows the thickness is much greater. The following are sizes of cross sections of parts of sashes for all ordinary sized windows:—

	Thickness.		Width.
Stiles	$1\frac{3}{4}$ in.	x	$2\frac{1}{4}$ in.
Top Rail	,,	x	,,
Bottom ,,	,,	x	4 in.
Meeting ,,	$2\frac{1}{8}$ in.	x	$1\frac{1}{2}$ in.
Bars	$1\frac{3}{4}$ in.	x	$\frac{7}{8}$ in.

546. The Joints of the Sashes are glued and the tenons secured with wedges, after which the faces are planed and cleaned off with sand-paper. The glass is next put in and the sashes are then ready for fitting and hanging in the frame. The fitting consists of planing off the superfluous width, so that the sashes may slide up and down easily between the pulley stiles, and in cutting off the rough horns at the top of the upper and bottom of the lower sash, and fitting so that meeting rails come together, and the bottom rail fits the sill. The outer edges of each sash are next grooved for some distance back from the horns at the meeting rails. These grooves are to take the sash cords. The process of hanging, briefly described, is as follows:—The top sash is taken first and weighed, and selection made of two weights, the combined weight of which is equal to that of the sash. The pockets in the pulley stiles are removed and the sash cords passed from the outside through over the pulleys; the inner ends are brought out again by way of the pockets, threaded through the tops of the weights, and secured in each by a knot. The weights are then pulled in through the pockets and up to near the pulleys or the inside of the pulley stiles, after which the other ends are secured with clout-headed nails in the grooves on the edges of the sashes. Allowance is, of course, made for the full amount of the slide down of the sash; that is to say, provision is made so that, when the sash is as low down as it can go, the weights on the inside shall not have quite reached the pulleys. Again, provision must be made that, when the sash is up at the top, the nails used for securing the cord to the grooves shall also be not quite up to the level of the pulleys, otherwise they would prevent enough of

the cord passing through to allow of the full upward slide. When the top sash is hung in place, the pockets are put in, and the parting beads are put in. It should be mentioned that portions of the bevel, at the ends of the meeting rails of each sash are removed, to allow of sliding past the parting beads. The bottom sash is then hung in the same way, but it must be remembered that the weights for this sash must be put in before the pockets are replaced. The stop, or inner beads (SB), are finally put in. Sketch B, Fig. 98, shows a balance weight (W), pulley (PY), and sash cord. The balance weights are of cast iron, and made in weights from 2 lb. upwards. Sash cord is a superior kind of hempen rope of small diameter. Before being used it should be well stretched, otherwise it will become loose afterwards.

547. Sashes for Solid Window Frames. These are called casements. They are made in either one or two leaves; and the stiles, top and bottom rails, and bars, are similar in size and shape of the cross section to those in the sashes for boxed frames. The jointing is also on the same principle. They are hung like a door, with butts to the stiles of the frame, and are arranged as a rule to open outwards. The example in large sketch, Fig. 99, is one to open outwards. This way of opening is far the best, it being possible to fully guard against the inroad of the rain-water. Sashes are, however, sometimes made to open inwards, in which case the rebate to receive them must be on the inside of the frame and special provision made, if the window is exposed, so that the junction of bottom rail with sash shall offer the best resistance to weather. If the sash is made in two leaves, the meeting stiles are rebated and beaded, as shown for a door at M, Fig. 96. Sashes for solid frames may be hung on pivots as described for a fanlight.

548. Sashes with Curved Heads. The examples given are rectangular in shape, but the form is by no means restricted to this, for sliding sashes are made, not only with curved heads, but also with curved faces, and those for solid frames may be of any shape. It is not possible to say more of these curved sashes than to mention that the pieces are as a rule jointed with butt joints, and secured either with the key shown at A, Fig. 67, or with the screw, described in Art. 374, *ante*.

549. Timber for Sashes. The following kinds of timber are used for sashes:—

Painted Work.—Baltic pine, oregon pine, clear pine, sugar pine, kauri pine, colonial pine, and redwood.

Polished or Varnished Work.—Cedar, Queensland maple, Pacific maple, silky oak, rosewood, blackwood, colonial beech, and kauri.

550. Finishing Round Windows. This part of the work can be best dealt with under two heads, as follows:—

(1) When frame is flush, or nearly so, with inner surface of wall.

(2) When frame is not flush with inner surface of wall.

(1) The first case is that mostly met with, being the finish of walls 9 in. or 11 in. thick, and consequently the kind, as a rule, in ordinary house building. A piece of board from 2 in. to 3 in. wide, with nosing on edge and at both ends, is put either with a groove into sill or just butted to sill. This is called a *nosing*. (See NB, Fig. 98.) A scotia or ovolo moulding, also with returned ends, is put under the nosing. The nosing is extended on each side of the frame to receive the ends of the architraves, which are put up the sides and over the head as in the case of a door (see Art. 512, *ante* re architraves.) If the sashes in the case of a box frame are thicker than $1\frac{1}{2}$ in. in a 9 in. wall, the frame will project out from inner surface of the plastering. This will render necessary a fillet to fill up spaces between back of architrave and wall. The fillet should be beaded on outer edge. (See sketch, Fig. 98, which shows finish on inside of box frame.) A solid frame could be finished similarly with the exception of the fillets at back of architraves, which would not be necessary.

551. When the Frame is not flush with inner surface of wall, that is to say, when it is back therefrom. In this case, which occurs in thick walls, lining boards (LB, Fig. 99) are necessary. The lining at the sill is called the "window board" or "nosing board," and is wider than the others, being arranged like the nosing to project out from wall, and extended on each side to receive the architraves. The linings at sides and head are only wide enough to come to edge of wall, and may be plain, as shown in the sketch, or panelled. Window linings are made much the same (the main difference being the absence of rebates) as those for doors, and are fixed in the same way. (See Art. 503, *ante*, and Fig. 94.) They are grooved into the frame and fixed to a ground at outer edges. The large sketch, Fig. 99, shows linings to a solid frame, but can also be taken as illustrative of the finish in the case of a box frame, for there would be no material difference were it the latter. The architraves are fixed to grounds which support the linings. In the example, Fig. 99, the linings are square, or at right angles, with the surface of the wall. In some cases they are put on the bevel outwards from face of frame. These are called "splayed linings"; when the head of frame is curved

the head lining is also of similar curve. The curved piece in such work is generally formed of a thin veneer with backing of wedged-shaped pieces, the whole being glued together.

552. Architraves for Window Openings. The inmost edges of window openings are finished with architraves (AR), as shown in sketches Figs. 98 and 99. The architraves are similar to those described for door openings in Arts. 511 and 512, *ante*, and fixed much in the same way. Where there are either nosings or window boards the architraves are butted or stopped on to them.

553. Timber for Linings and Architraves of Window Openings. The timbers used for these parts are usually either oregon, redwood, kauri or colonial pine in cases where the work is to be painted. Any of the timbers mentioned in Art. 510 as suitable for jamb linings, will, however, do. In cases where the work is to be polished or varnished, the timbers for door and window openings, and other internal fittings, should be selected with a view to a pleasing effect as a whole.

554. Shutters are framed covers or screens used for window and casement openings to afford either shade from sun, protection from the rain, or resistance to fire or robbers. They are made in either one or more leaves, and are either hung like a door, or made to slide either into cavities at either sides or above or below opening. They may be divided into two kinds:—

(1) External Shutters.
(2) Internal ,,

555. External Shutters. These are sometimes made like either a *framed and ledged,* or a *bead and flush panelled* door, with the timbers very thick, so as to resist violence, or very rough weather. Outside shutters are also, where extra strength is required, or where protection from fire is needed, made of stout iron plates. The latter are, however, only used in large buildings, subject to extra risk from fire in dangerous parts of cities, while heavy wooden shutters are very seldom used in house building, because the object as a general rule is only to provide shade from the sun and protection from rain. Sketch B, Fig. 99, shows portion of a shutter of the kind generally used. They are made generally in two leaves, each of which is a light frame filled in with slanting laths or "louvres." In cases where the window is of ordinary size, there would be a top, middle, and bottom rail in each leaf, but for casement and other openings of fair height sufficient rails would be put in between top and bottom to allow of a spacing apart of about

3 ft. The stiles (S) and top and intermediate rails (R) would be about $2\frac{1}{2}$ in. x $1\frac{3}{4}$ in. in cross section, while the bottom rails would be from 6 in. to 9 in. wide, and the same thickness as the others. The louvres (L) are generally $\frac{3}{8}$ in. thick, and of a width sufficient to give enough of cover, one over the other; and they are housed for about $\frac{1}{4}$ in. into the stiles. The edges of the stiles and rails next to the louvres, are beaded on both sides of the frame. Louvre shutters, as they are called, are hung to small pieces of timber about $1\frac{1}{2}$ in. x $1\frac{3}{4}$ in. (see HS, sketch B, Fig. 99) in cross section, or whatever may be the thickness of the shutters, and are secured with screws to the outer facing of box frame, or to stile of solid window frame, or casement door, as the case may be. Head pieces of the same scantling are fixed at head of frame, and connected to tops of side pieces with a butt and mitre joint. These side and head pieces are called "shutter hanging stiles and heads." The shutters should be hung to open back against the outer face of wall. To accomplish this a kind of hinge known as a "Parliament hinge" and shown at PH, sketch B, and at sketch C, Fig. 99, must be used.

556. Timber for Louvre Shutters. Cedar, baltic pine, and redwood, are good kinds for the frames; while cedar or baltic pine are suitable for the hanging stiles and beads. Redwood is by far the best for the louvres.

557. (2) Internal Shutters. These are generally made in very narrow leaves, each of framed and panelled construction, which are hung together in two sets like folding doors. They are made to hang this way, so that they may be folded back into boxes or casings at each side of the opening, and consequently be out of the way when not in use. A sketch showing a horizontal section through the side of a window opening, with a box frame fitted with internal folding shutters, folded back in the casing, is shown at D, Fig. 99. Shutters also of framed and panelled construction can be made of the size of the sashes, and arranged to hang like the latter in a second box frame inside that for the sashes, and disappear when not in use into a cavity at foot or head of opening. Internal shutters are hardly needed, and indeed are very seldom used in the climate of this country.

558. Skirting. The boards put round to cover the joints of the walls with the floor, and to form a base for the walls, are called skirting boards. In design the skirting boards may, according to circumstances, be either *plain, moulded* or *double-faced and moulded.*

559. Plain Skirting consists of a piece of board about 6 in.

wide and 1 in. thick, with the top edge either chamfered or beaded. *Moulded skirting* ranges from about 7 in. to 9in. wide, and has an ogee or ovolo, or some such moulding, on the top edge. Sections of moulded skirting boards are shown at R, Fig. 72, and at SK sketch, D, Fig. 90. *Double-faced and moulded skirting* is the most elaborate form. The name, double-faced, is given because the face of the board has two large, plain surfaces. This kind is generally made in two pieces, so as to obviate the disadvantage of having one large piece of timber, the pieces being grooved and tongued together, as shown at S, Fig. 97, which illustrates a double-faced skirting.

560. Timber for Skirting Boards. In polished or varnished work the timber used for skirting is generally the same as that in the architraves. Pine timber, such as redwood, kauri, baltic or oregon, are used when the work is to be painted.

561. Fixing Skirting Boards. As a rule, skirting boards, after being scribed so that the lower edge fits the floor, are secured to walls with nails driven into grounds or plugs, the latter being spaced not more than 18 in. apart. The lower edges should not be nailed to the floor, because of the danger of splitting the skirting boards if shrinkage should take place. In the best class of work the skirting boards are grooved into the floor (as shown in Fig. 97), thus providing for movement, due to shrinkage, as well as helping to keep the skirting in place.

562. Surbase and Dado. A *surbase* consists of moulded railing, sometimes referred to as a chair rail, put round the walls at from 2ft. 9in. to 4 ft. above the floor. The *dado* is the portion of wall surface, or boarding, or panelling, between the skirting and the surbase. In large public buildings the skirting, dado, and surbase become imposing features, and the height of the surbase is often much more than 4 ft. The dado, as a general rule, is composed of veneer panels or of 6 in. x 1 in. or 4 in. x 1 in. T. and G. and B. boards, either diagonally or upright, and nailed to framing of grounds. The sketch, Fig. 97, shows a dado of framed and panelled work with a double-faced skirting and moulded surbase. An inexpensive form, and (if the walls be papered) a very good effect can be got by putting strong paper with relieved patterns, such as "Lincrusta-Walton," for the dado. The surbase is often made quite plain (*i.e.*, a plain board about 3 in. x 1¼ in., with beaded top and bottom edges), and put low enough to catch the tops of backs of chairs. In such cases it is put up mainly with the object of preventing damage to the walls, and is called a *chair rail.* It is worth mentioning that in internal decoration

the term "dado" is often meant to include the skirting and surbase, as well as the dado proper. Skirtings, timbers, dados, surbases, and chair rails should be fixed after the plastering is completed.

563. Picture Rails are pieces of moulded timber usually about 3 in. x 1 in. put around the upper part of walls at the level of the head of door architraves, or higher, according to tests. They are used as their name implies—to suspend pictures from. They are also, as a rule, considered as a part of the internal decoration, and made to form the lower edge of a frieze which extends upwards to the ceiling or cornice.

STAIRS

564. Series of Steps for ascending from one story to another in a building are called *stairs*. The *staircase* is the structure surrounding or enclosing the stairs. *The kinds of stairs* are as follows:—

(*a*) Straight
(*b*) Dog-legged
(*c*) Open Newel
(*d*) Geometrical
(*e*) Circular

Note.—The various sketches showing the different kinds of stairs in Figs. 101 and 102 are merely diagramatic, all details being omitted.

565. A Straight Stair is shown at sketch A, Fig. 101. As will be seen, it consists of a number of steps, one above the other, and rising in the one direction. This kind is useful only when the total rise is small, because if the stair is a long one they are tiring to ascend, and, besides, they require a lot of space for the "going," *i.e.*, for the length. If, however, "landings" be put in to divide the total length into short flights, the straight stair can be made easy of ascent, and also a very imposing structure.

566. A Dog-Legged Stair is shown at sketch B, Fig. 101. This kind of stair is divided into two flights going in opposite directions. A stair of this description may have either a landing as shown in the sketch, or *"winders."* Winders should, however, if possible, be avoided, for at the best they are uncomfortable, if not positively dangerous.

567. Open Newel Stair. Sketch D, Fig. 101, shows an example of this kind of stairs. It will be seen that it consists of two flights in opposite directions, like the dog-legged stair,

but it differs from the latter, inasmuch as that the "outer" strings are not directly above the other, consequently, it requires two newels at the landing—one to finish lower, and one to commence upper, flight. A variety of this stair occurs when a third flight is put in between, and at right angles to, the upper and lower flights. (See sketch E, Fig. 101.)

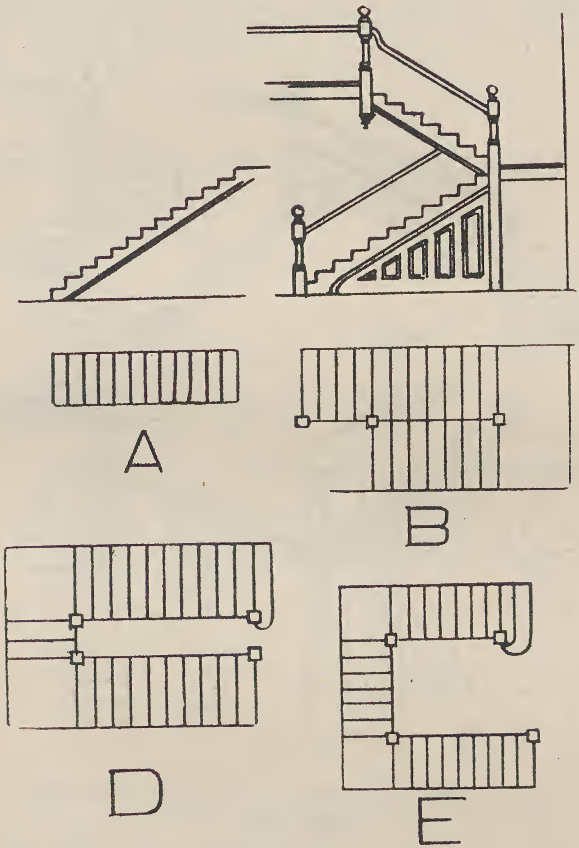


FIG. 101

568. Geometrical Stairs. Stairs of this class have "winders" and are arranged with an opening, or *"wellhole,"* between the flights, and without newels, the outer string being continuous from bottom to top. An example is shown by sketch A, Fig. 102.

569. Circular or Spiral Stairs. An example of this kind is shown by sketch B, Fig. 102. The steps are all "winders"

converging from the outside to the centre. There are two kinds of circular stairs, viz., *circular geometrical,* when the stair has an "outer string" and a "well hole"; and *circular newel,* when the stair has a centre newel into which the steps converge. The sketch shows a circular stair with a newel. The various parts of stairs will be found described in the following articles.

570. Steps. Sections of stair steps are shown by the large sketch in Fig. 105, in which T indicates the tops, or "*treads,*"

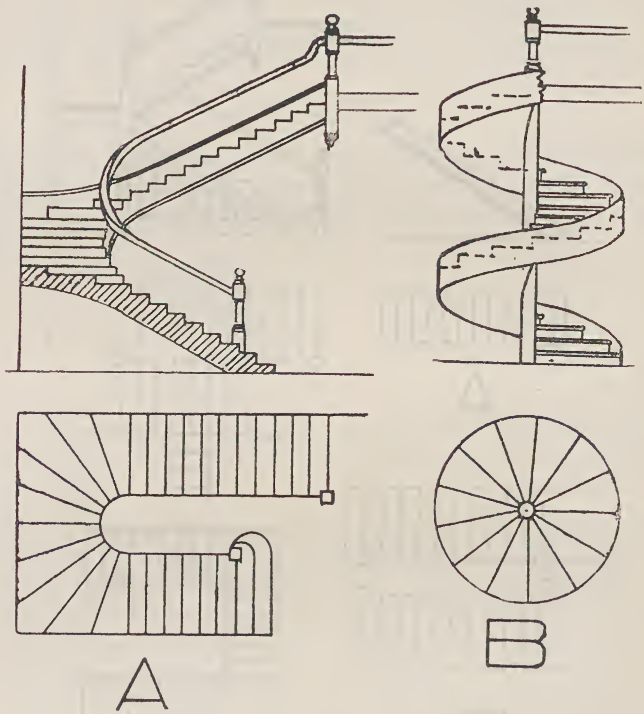


FIG. 102

and R the "*risers,*" or faces. A step of this kind of stair would therefore be composed of a tread and a riser. (In very common stairs the riser is omitted, so that the step is a tread only.) Treads for stairs of ordinary houses are made 1¼ in. thick, but for first-class work the thickness is made from 1½ in. to 1¾ in. The outer edge of tread is nosed (as shown by the sketches Fig. 105). Risers are made from 1 in. thick in ordinary stairs to 1¼ in. for the better kind. The large sketch, Fig. 105, shows different methods of joining the riser to tread.

To further strengthen the joint between tread and riser, small blocks are glued and secured in the internal angle. (See BL, Fig. 105.) Figs. 103 and 104 show methods, usually adopted, for fixing steps to strings. In Fig. 103, the steps are housed into both strings. In Fig. 104, they are housed into one, and cut, mitred, and bracketed on to the other. In some cases they are cut, etc., on to both strings. The details of methods for securing steps to strings are described in Art. 571. The ordinary steps in a flight are called *"fliers."* Those which radiate from a newel, or a well-hole, are called *"winders."* The latter

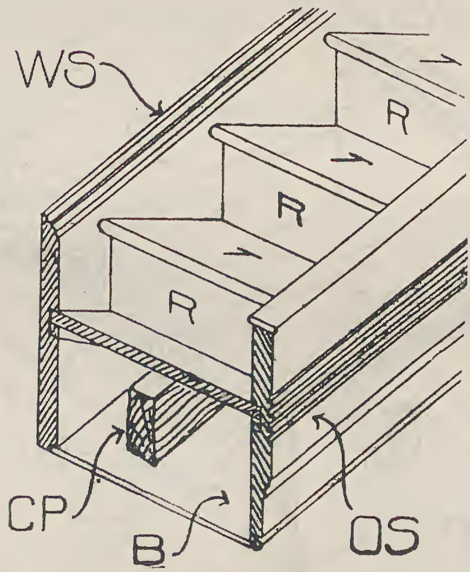


FIG. 103

should be avoided as much as possible, but where absolutely necessary they should be of the same width as the fliers at 18 in. from the outer string or newel. The *"going"* of a stair is the horizontal distance from face of one riser to that of the next one, while the *"rise"* is the perpendicular distance from top of one tread to the top of the next one above. It should be remembered that steps which are both wide and high are very fatiguing to ascend, so that when designing stairs it is necessary to have a wide tread, if the rise is small, or *vice versa.* A very good rule for the proportion is: Width of tread, multiplied by height of riser, should approximate to, or equal, 66 in. The width of the tread should not be less than 9 in., but in important stairs should be more—12 in., tread and 5½ in. rise

giving an ideal step. Sometimes the lowest one of the steps in a stair is made larger than the others, and brought out at the end in a pleasing curve or "sweep." Such is called a "curtail" step. The construction of a step of this description is shown by sketch B, Fig. 107, by which it will be seen that the outer end of the riser is reduced to a veneer about $\frac{1}{4}$ in. thick, and bent round and permanently secured to an inside block.

571. Strings. These are the pieces of timber at the sides of a stair flight which support the steps. The piece put against

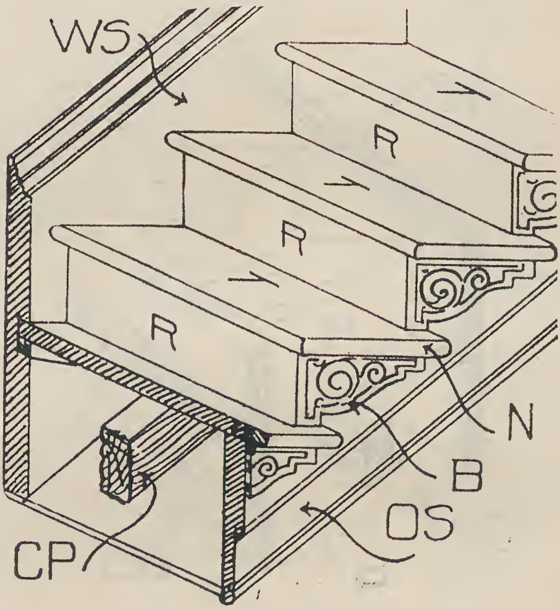


FIG. 104

the wall is called the "wall string," while that on the outer side of the flight is called the "outer string." When a flight is put between two walls both of the side pieces are wall strings. A wall string (WS) and outer string (OS) are shown in sketches, Figs. 103 and 104. Strings are classified as follows, according to the method of finishing and securing steps to them :—

(1) Close or housed strings.
(2) Open or cut ,,

When the steps are let, or housed, into, the string and the top of the latter left so as to be parallel to the lower edge it is called a *close or housed string*. Examples of housed strings are shown in Figs. 103, 104, and 105. In sketch, Fig. 103, both

wall and outer strings are housed. When the outer string is housed, it is finished on the outer surface after the style of the one in the sketch, Fig. 103, or it may be set out in imitation of panelling. The large sketch in Fig. 105 shows method of housing and securing the steps in the case of a housed string. The sketch is a view from the underside. As will be seen, the steps and risers are housed into the string (S) to a depth of from $\frac{1}{2}$ in. to $\frac{3}{4}$ in., as the thickness of string may allow, and tightened up and held in place by wedges (W) driven in behind

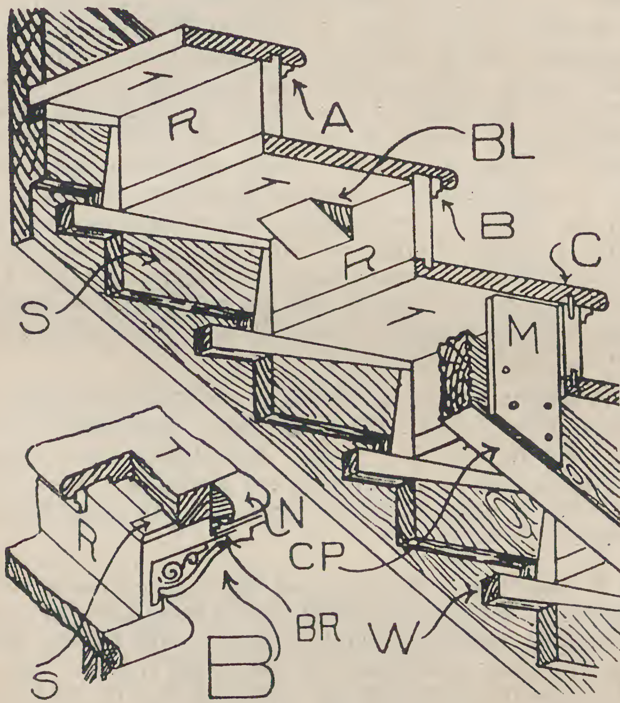


Fig. 105

them, the whole of each joint being well glued, and the wedges further secured by being nailed to the string. In the sketch, Fig. 104, the outer string (OS) is an open one, being "*cut, mitred, and bracketed.*" An open or cut string, as its name implies, is cut away so that the end of each step is shown. The sketch B, Fig. 105, is the end of a step on an open string. The corner is removed to show the arrangement of the different parts. (S) is the string on which the tread (T) rests. (R) is the riser rebated on to the string, and carried on so as to mitre with the ornamental bracket (BR). (N) is the nosing

piece planted on, so as to return the nosing of front edge round the end of tread. In some cases the ornamental brackets (BR) sketch B, Fig. 105, and B, sketch, Fig. 104, are omitted. The risers would then be mitred to the string instead of rebated, as shown in the sketches. Rough strings or "carriage pieces" (CP in sketches Figs. 103, 104 and 105) are put in under the steps midway between the strings, to form an additional support. They should extend from bottom to top of the flight, and be well secured at the ends. Pieces of timber (M sketch, Fig. 105) are nailed to the carriage pieces and butted up to under surface of each tread. A *"wreathed"* string is one which is continuous, that is, without newels up two or more flights. The outer string in the geometrical stairs, shown in sketch A, Fig. 102, is an example of a wreathed or continued string for two flights. The wreath, or turn, can be made (as shown by the sketch A, Fig. 107). The turning portion of the string is, as shown by the sketch, reduced so that there is only a veneer about $\frac{1}{4}$ in. thick on the outside. This veneer is turned on a half cylinder to the double curvature required, and backed up with pieces fitting together like arch blocks and glued. The wreath is then cut for threads and risers. It may be mentioned that the wreath is made separately and then jointed to the straight portions of the string.

572. A Flight is a series of steps one above the other. The straight stair at A, Fig. 101, is a flight. The stair at B, Fig. 101, has two flights. The "going" of a flight is the horizontal distance from face of its bottom riser to the face of that of the top. It will be noticed that a flight has one more riser than the number of treads.

573. A Landing is a horizontal space intervening between two flights, or the space at the top of a stair. Properly speaking, the name landing should be given only to the space at the top of a stair, the others being called spaces. The space equal to the width of a flight (as at sketch D, Fig. 101) is called a $\frac{1}{4}$ space. That equal to width of both flights (as at sketch B, Fig. 101) is called a $\frac{1}{2}$ space. Landings or spaces are constructed similarly to floors, for which see Articles 380 to 400, *ante.*

574. Soffit of Stairs. The soffit is the under surface of a flight, or landing. It may be formed either with fibrous plaster, timber, wall board or with metal plates. Fibrous plaster or wall board is put on in the same way as for a ceiling. Timber soffits are formed either with lining boards for ordinary stairs or panelled work for the better kinds. The lining boards may be put on square with the strings, or diagonally, as the taste

of the designer may decide. The panelled soffits are framed and panelled on the principle (as described in Art. 492, *ante*), the division and arrangement of the panels being matters controlled by the particular style of the design. Thin pressed

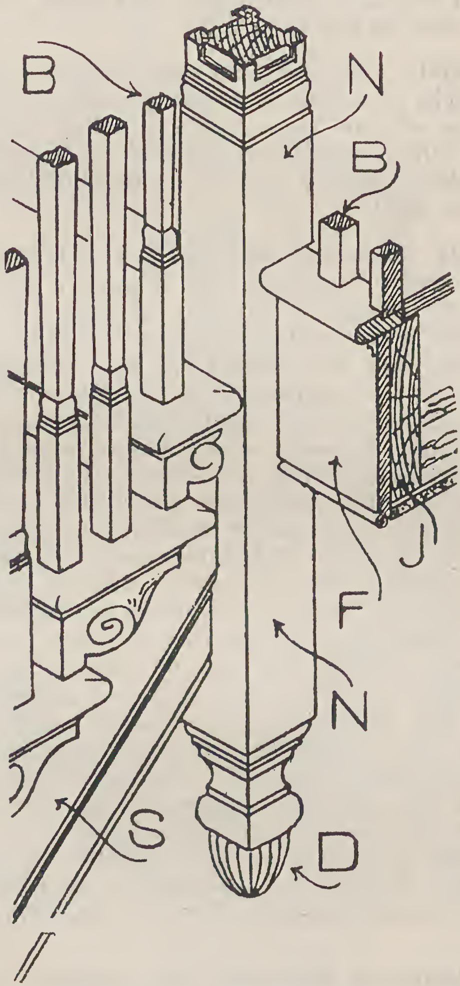


FIG. 106

metal plates are sometimes used for stair soffits. The plates are made in plain or ornamental designs, as the case may require, and secured to strings and carriage pieces, firring pieces being used as required.

575. Head Room. Provision should always be made for enough of perpendicular space, so that the head of anyone ascending the stairs shall not be liable to catch against the edge of the landing or soffit of stairs above. This perpendicular height or space is called the "head room," and it should, if possible, never be less than 7 ft.

576. Spandrel. The triangular space under outer string of the lowest flight of a stair is sometimes filled with boarding, or, in the case of good stairs, with panelling, to form a cupboard. This filling is called a *spandrel.* A panelled spandrel is shown at sketch B, Fig. 101. The panelling would be about $1\frac{1}{2}$ in. or $1\frac{3}{4}$ in. thick.

577. Newels. These are the posts put at bottoms and tops of flights to secure handrails, etc. Properly speaking, however, the term belongs to the central post from which the winders radiate in a circular newel stairs. Newels are shown in the sketches, Figs. 101, 102 and 106. Sometimes the portions, not occupied by the abutments of strings and handrails are turned or square-moulded, and the tops rounded off as spheres or ovals. In some stairs, the newels are plain, the edges being stop-chamfered. In stairs of imposing character, such as those for public buildings, the newels are the portions to receive special ornamentation, and they are turned, moulded and carved in the most elaborate manner. The strings are housed and tenoned into the newels, and the joints secured with pins and glue. Newels at landings are notched on to the outer joist of the latter. Some idea of the relative positions of string newels and landing may be obtained by the sketch, Fig. 106, which represents a top corner of a flight in an open newel stair. N is the newel, the top part of which is cut off. S is the string. The outer joist of the landing is shown at J, covered by the facia board, F. BB are lower portions of balusters. In this case the bottom of the newel is finished with a "drop," *i.e.,* a moulded or turned end. The newel at top of lower flight is sometimes carried down to the floor (as shown at sketch B, Fig. 101). Newels are made upwards from 4 in. x 4 in. in cross section; 6 in. x 6 in. being a common size.

578. Handrails and Balusters. The handrail is the piece of timber put at a convenient height for the hand at the side to act as a support during ascent, and to prevent falling over side of stairs. The rail should be of such timber as Queensland maple or cedar, which can be successfully polished. The rail should be parallel to line of nosings of each flight, but may be curved at ends, to make a graceful finish against newels (as

shown in sketches B, Fig. 101, and A, Fig. 102). When the rail is continuous, as for geometrical stairs (see sketch A, Fig. 102) it is called a *wreathed handrail,* the portion at the turn

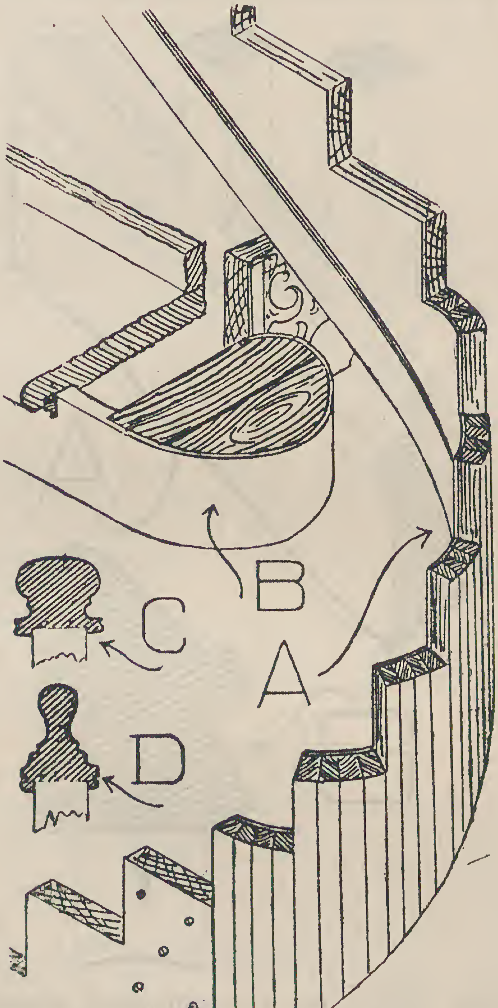


FIG. 107

being the "wreath." An ogee bend like that at the top newel in sketch B, Fig. 101, is called a *swan's neck.* A single turn, convex in form, is called a *knee,* while a concave turn is called a *ramp.* Handrails range in cross section, from a plain oval to

the elaborately moulded. Small sketches of cross sections of handrails of common patterns are shown at C and D, Fig. 107. A very good style of handrail is shown in cross section by sketch B, Fig. 108. The main consideration is to have the top

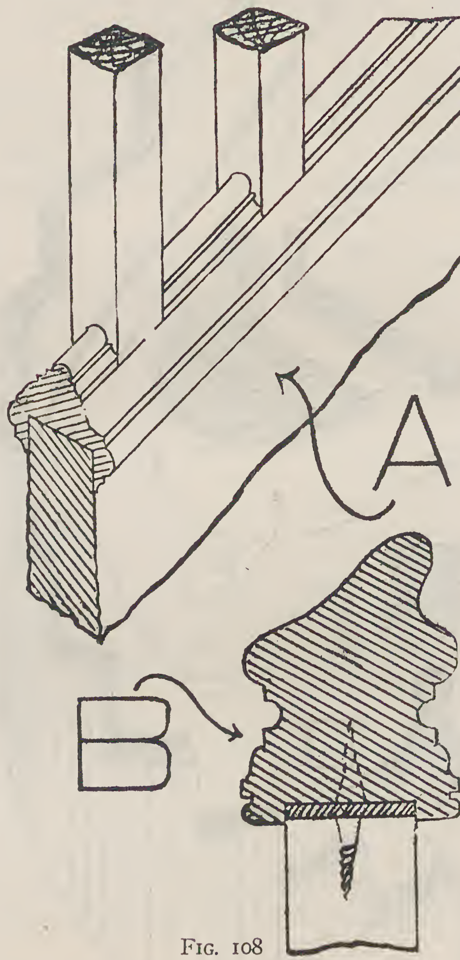


Fig. 108

of rail of a shape that it may be comfortably grasped by the hand, and there should be no sharp edges in this portion. Handrails for common stairs may be 4 in. deep and 3 in. wide, the top being reduced to a round about 2¼ in. in diameter. The top of the handrail should be 3 ft. above landings, while the height above nosing should be about 2 ft. 7½ in. The handrail should be housed and tenoned into the newels.

579. Balusters are the small posts, placed at frequent intervals to support the handrail, and also to help to prevent falling over the side of the stairs or landings. Balusters range upwards from 1½ in. x 1½ in. in cross section, 2 in. x 2 in. being the usual size. They are either plain or moulded to match the newels. If the string is an open one the balusters are either housed or dovetailed into the treads. (See sketch, Fig. 106.) When the outer string is close or housed (as at Fig. 103) the balusters would be cut on to the upper edge of the string. In stairs of a good description the portion of close string between the baluster is moulded, (as at sketch A, Fig. 108.) The best way to secure the balusters to the handrail is by means of an iron bar, the width of the balusters, about ¼ in. thick, and of the length of the rail, and secured with a screw to head of each baluster and also by screws at frequent intervals up into the rail. A cross section of a handrail and balusters secured in this way is shown at sketch B, Fig. 108. In common stairs the heads of the balusters are nailed to the handrail. When the string is an open one, two balusters are put on the end of each tread (as shown by the sketch, Fig. 106); but in any case the balusters should not be spaced more than 5 in. apart.

Sometimes the space between the handrail and string is filled in with solid timber flush panels. The panels are fixed to rough framings, and are usually ¾ in. thick.

580. Timber for Stairs. The following timbers are used for this purpose:—

Painted work: Kauri, oregon, colonial pine, colonial beech.

Polished or varnished work: Cedar, Queensland maple, Pacific maple, silky oak, blackwood, rosewood, red bean and colonial beech.

SHOP FRONTS

581. Shop Fronts, though differing in matters of detail, are all very much the same as regards general arrangement and construction. The sketch, Fig. 111, shows half plan and elevation of a typical shop front with two windows, the entrance door being in from the line of the front. The stiles for the door frame are made of large scantling (about 6 in. x 6 in.), so that they may afford ample abutment for the window sashes, and they are carried up either to the level of soffit over entrance or to shop ceiling. In a door frame of this kind the head as well as the transom would be tenoned into the stiles. Casements, as shown in the sketch, and at G, Fig. 96, or sash door in one leaf, as at F, Fig. 96, are the kinds of doors used for shop entrances, but generally they are all glass, i.e., one

single panel of glass. Solid panelled doors like those at B, Fig. 96, or M, Fig. 95, are sometimes used. For detail description of doors and door frames see Arts. 497 to 532, *ante*.

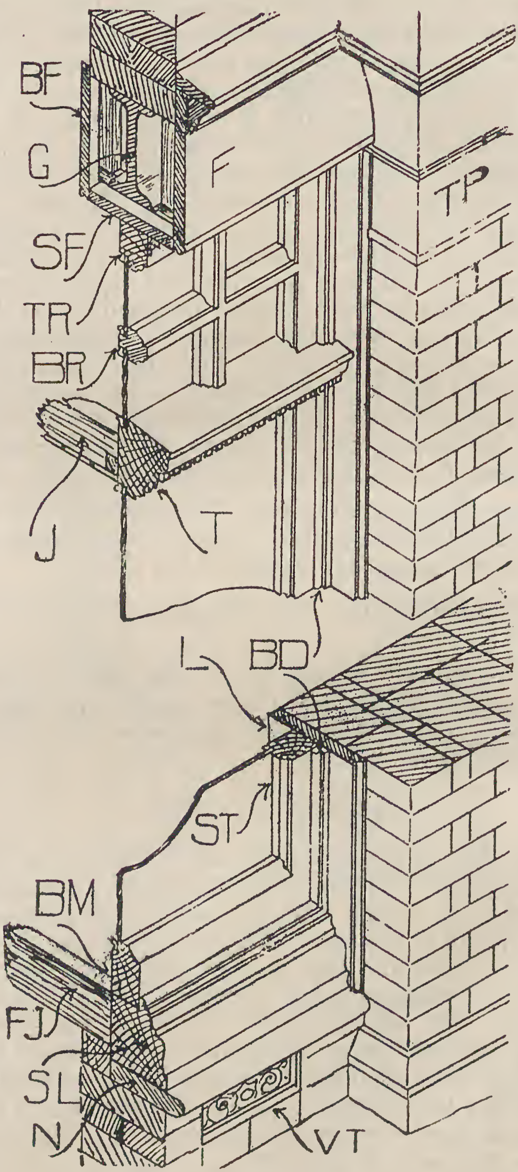


Fig. 109

582. Shop Windows. The sketch, Fig. 109, shows isometrical views of portions of shop windows. The vertical section is on a vertical plane taken through at the position indicated by the line CD on the plan in Fig. 111, while the horizontal section is made at the level of EF. Linings (L) about $1\frac{1}{2}$ in.

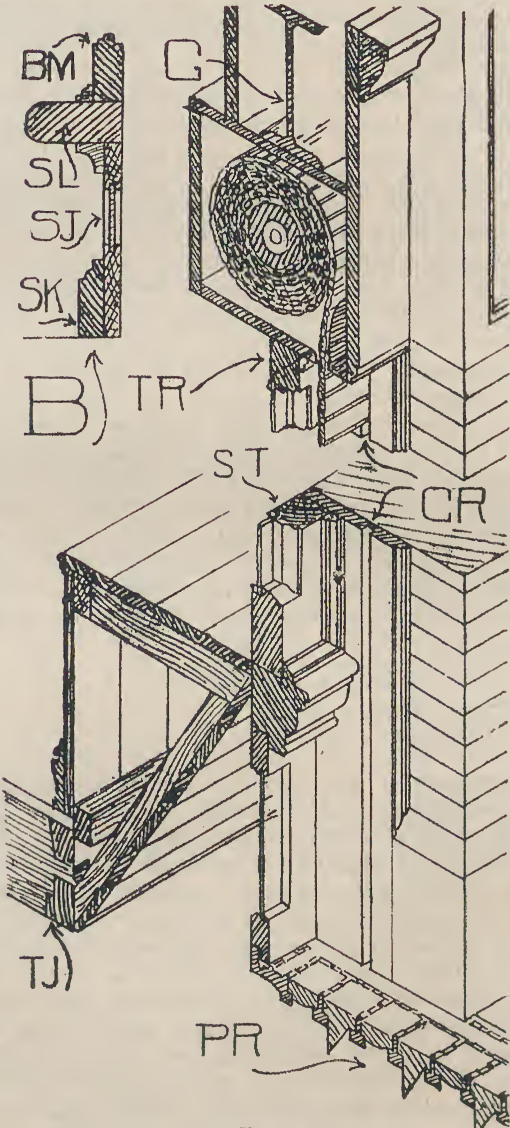


FIG. 110

thick, with nosing or ovolo on outer edges, are secured by means of plugs to sides of piers. The tops of these linings are grooved into the soffit (SF) of the casing of the girder (G) which spans the opening. The timber sill (SL) is put resting on a slate or marble nosing which in its turn rests on a brick-work base. Sometimes the base is of masonry and the nosing omitted, the sill being put directly on the base. The scantling of the timber sill may be about 8 in. or 9 in. high, and 7 in. or 8 in. wide, the outer surface being moulded as shown. This sill is housed into the lining against which it abuts, mitred at the corner and housed at the inner end into the door post. The bottom rail (BM) of the sash is put resting in a rebate on the top of the sill. The section sketch B, Fig. 110, shows a method adopted when the bottom rail of the sash is to be at some height above the base course. SJ is a piece of framed work called a stall board, the panel being generally a cast-iron grill so as to allow of ventilation. SL is the sill on which the bottom rail of sash (BM) rests. In cases where the building has a basement the stall board is formed of swinging sashes with glass in them, as shown by large sketches, Fig. 110, so that light and ventilation may be obtained for the basement. The shop window sashes are made with stiles (ST) bottom rail (BM), and top rail (TR) (sketches in Figs. 109 and 110) rebated and moulded like an ordinary sash (excepting, of course, that the rebates and mouldings are on a larger scale), and they would be jointed together, as shown in Fig. 100. The top of the bottom rail is, however, generally bevelled instead of moulded. The usual sizes of parts of a shop window sash are as follows:—

Bottom rail, 6 in. x $2\frac{1}{2}$ in.
Stiles, 4 in. x $2\frac{1}{2}$ in.
Top Rail, 4 in. x $2\frac{1}{2}$ in.

It is the general practice to divide the upper part of the sash into a number of smaller panes. This is done by putting in a transom (T) and bars (BR), as shown in the sketch, Fig. 109. The glass should be fastened in the shop-window sashes with beads, secured with screws (as shown in the sketch). In very large windows the best plan is to have the rebate for the glass on the outside, the beads being part of the moulding. A small bead or ovolo (BD) to match top mould of sill, and to intersect with it, is put round joint of sash with lining. The sash at each side of the entrance is, of course, made the same way, and either the two stiles mitred together at the corner, or an angle bar (as shown by sketch B, Fig. 111) is put in. In modern work the bars are as small as possible, and are often covered with nickelled metal. The front of the

casing of the girder forms a fascia, and is ornamented with mouldings and capping piece. The space over the area between the shop door and girder is usually ceiled with a framed and

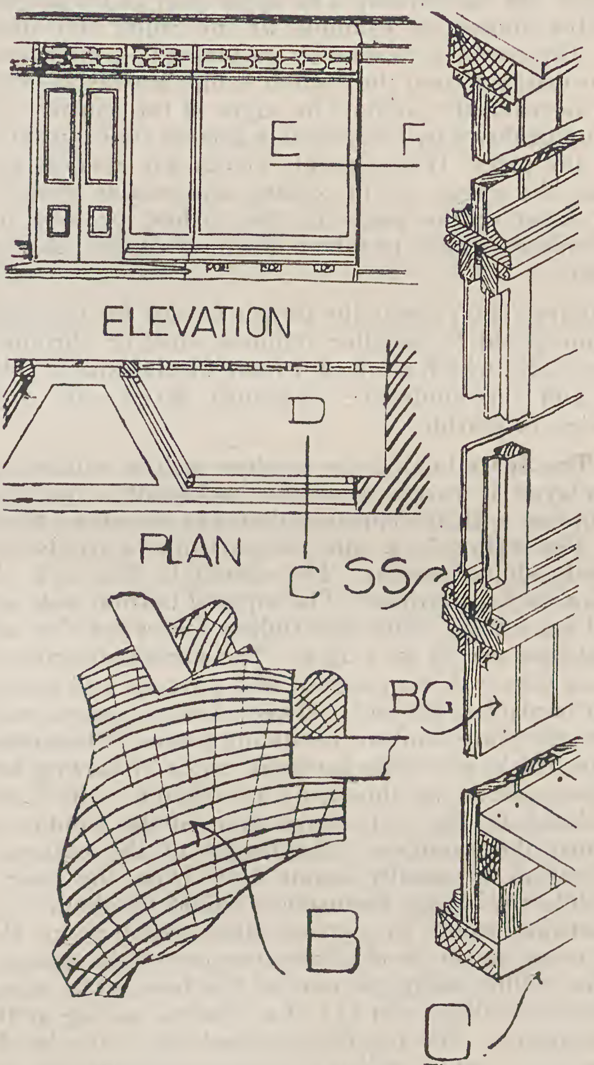


FIG. III

panelled soffit. If the shop front is unprotected by a veranda the capping of the fascia should be covered with lead, and flashed to the wall above. Revolving shutters, formed with thin

timber or iron laths hinged together, are used for the protection of shop windows. They are rolled up on a spring roller into a space either under or in front of the girder which spans the opening of the shop front. The upper part of the large sketch (Fig. 110) shows an example of the roller put under the girder. The recess is formed by keeping the soffit board down for some distance from the bottom flange, the fascia being deep enough to reach the soffit. The edges of the shutter would be guided up or down by running in a groove (GR) in the linings against the piers. If in separate pieces, for window and door entrance, the edges of the shutter are run in grooves in a column fixed at the angle of the sashes, or in a movable vertical piece, which is taken down when the shutters are rolled up.

In modern shop fronts the timber fixings for the glass have been superseded by smaller stainless steel or chrome plated metal sections, which allows for more display space. The stall-boards and surrounds are frequently faced with structural glass, tiles, or marble.

583. The Space behind the window sash in which the goods are displayed is cased in at the back with a partition put across in line with the entrance door (as shown by the plan in sketch, Fig. 111). As a rule the partition is partly boarding and partly sliding sashes. The sketch C, Fig. 111, shows a section of such a partition. The top and bottom rails or plates are of 4 in. x 2 in., while the sliding pieces for the sashes to slide between are 5⅜ in. x 1¼ in. The upright boards are 4 in. x 1 in. or 6 in. x 1 in., tongued and grooved and beaded, and are kept in place at the ends between ovolo or scotia mouldings nailed to the plates and to the sliding pieces. The sashes (SS) are 1½ in. thick, and slide between stop and parting beads on the sliding pieces, as shown by the sketch. The lower part of the sketch C, Fig. 111, shows floor of the window coming up against the partition. The height of the bottom of the sliding sashes is usually about 3 ft. from the floor of the shop, while the sashes themselves would be about 5 ft. high. The partition would be carried either right up to the shop ceiling, or up to the level of the transom of the window sash, a window ceiling being put over at this level. The sketch, Fig. 109, shows a ceiling joist (J) of a window ceiling at the level of the transom. The partition carried up to the level of the transom of a window ceiling is the best, because the shop can be lighted and ventilated from the portion of the shop window above the transom. In large windows the sliding sashes are not used. A partition composed of 3 in. x 2 in. or 4 in. x 2 in. studs and rails, with upright boarding to a height of 6 ft. or

7 ft., and the remainder of glass in fixed sashes being adopted instead. In such a partition, access is got to the window space by a ledged door about 1 ft. 6 in. or 1 ft. 9 in. wide, put in the lower part. In shops such as chemists, jewellers, confectioners, etc., where the fittings are of the cabinet work class, the casing-in of the window space is done in a very much better style than just described.

SHOP COUNTERS AND PARTITIONS

584. Shop Counters. Sketches A and B, Fig. 112, are examples of shop counters. Sketch B is a cross section of a plain counter, made with 3 in. x 2 in. framing, top about 1¼ in. thick, with a thumb mould on outer edge, and a front composed of flush veneer panels or of 4 in. x 1 in. or 6 in. x 1 in., tongued and grooved and beaded, or V jointed, upright boarding, finished at the lower part with a skirting. There are many methods of framing up the inside frame, but the most common is to have a frame, back and front, each composed of 3 in. x 2 in. top and bottom pieces and uprights, the latter being spaced about 4 ft. apart and tenoned into the former. The back and front frames extend each the whole length of the counter, and are connected together by crossbearers, also of 3 in. x 2 in., placed top and bottom at the positions of the uprights. The cross bearers are tenoned or dovetailed into the tops and bottoms of front and back frames. Cross bearers are also put in to carry the shelves. The inside has a floor about 4 in. up from floor of shop, and either one or more shelves between the floor and the top. The sketch shows an example with one shelf inside. The sketch A is an example of a more elaborate counter. The framing of the inside is very similar to that of the kind just described, but the front is framed and panelled work, with a slope inwards towards the bottom. The thickness of the panelled work is about 1½ in., and the panels are ½ in. thick, with bolection mouldings. Sometimes the panels are raised (as described in Art. 523, and shown by sketch D, Fig. 95). For detail description of framed work and finish of panels, see Arts. 518 to 523, and sketches A, B, C, and D, Fig. 95. Curved and fluted pilasters are planted on to, and secured to, the front at intervals of about 4 feet, the skirting of the lower part of the counter being returned round their lower portions. The top should be 1½ in. thick, with the outer edge moulded. The sketch shows the principle of the general finish of such a counter. The design can, of course, be varied by having the front perpendicular, and straight, instead of curved pilasters. can be used. The usual height of a shop counter is 3 ft., while the width is about 2 ft

6 in. Counters for special kinds of business premises are sometimes higher and narrower, as for an hotel bar, a cafeteria, or a milk bar, while in other cases, though not being very high, they are very much wider, as for a bank.

585. The kinds of Timber used for counters are as follows:—

Inside Framing: Baltic, oregon, kauri or colonial pine.

Tops: Kauri, cedar, blackwood.

Note.—The tops should be polished if possible, as paint will wear off.

Fronts. *Varnished or polished works*: Cedar, Queensland maple, Pacific maple, blackwood, colonial beech, red bean, and others of the fancy and figured Australian timbers. Kauri pine and imported fancy timbers are also used.

Painted Works: Redwood, kauri, oregon, baltic, or colonial pine.

586. Partitions. Only partitions used for dividing shops and offices will be noticed under this head, those for lath and plaster work, etc., having been dealt with in Art. 458. Common partitions are made with 3 in. x 2 in., or 4 in. x 2 in. studs and rails, and uprights 4 in. x 1 in., or 6 in. x 1 in., tongued and grooved and beaded or V jointed boarding. The studs are placed about 3 ft. or 4 ft. apart and rails at bottom and top. If the partition is of considerable height intervening rails are spaced about 6 ft. apart. The boards are secured by being let into grooves in the rails and studs, or with beaded fillets or mouldings at both sides (as shown in the sketch C, Fig. 111). When the boards are let into grooves the edges of the studs and rails are either beaded or stop-chamfered. Partitions made on the same principle, as above, but with the upper part composed of glass in sashes, the latter fixed with stop beads, are also much used, and can be recommended where division, without excluding light, is needed. A better class of partition, such as used for subdivision of office rooms is shown by sketch C, Fig. 112. Such a partition would be composed of framed work about $1\frac{3}{4}$ in. thick, the panels being mouldings. For description of framed and panelled work see Art. 492, *ante*, and for panels see Arts. 518 to 523, *ante*, and sketches A, B, C, D, Fig. 95. In the example shown the upper panels are of obscured glass secured in place with beads. Skirting boards are put on each side at the joint of the partition with the floor. A partition like the one in the sketch (C, Fig. 112) would be from 6 ft. to 8 ft. high, and would have

the top finished with a moulded capping piece. Sometimes framed and panelled partitions are carried right up to the ceiling, in which case they require to be stiffened at intervals

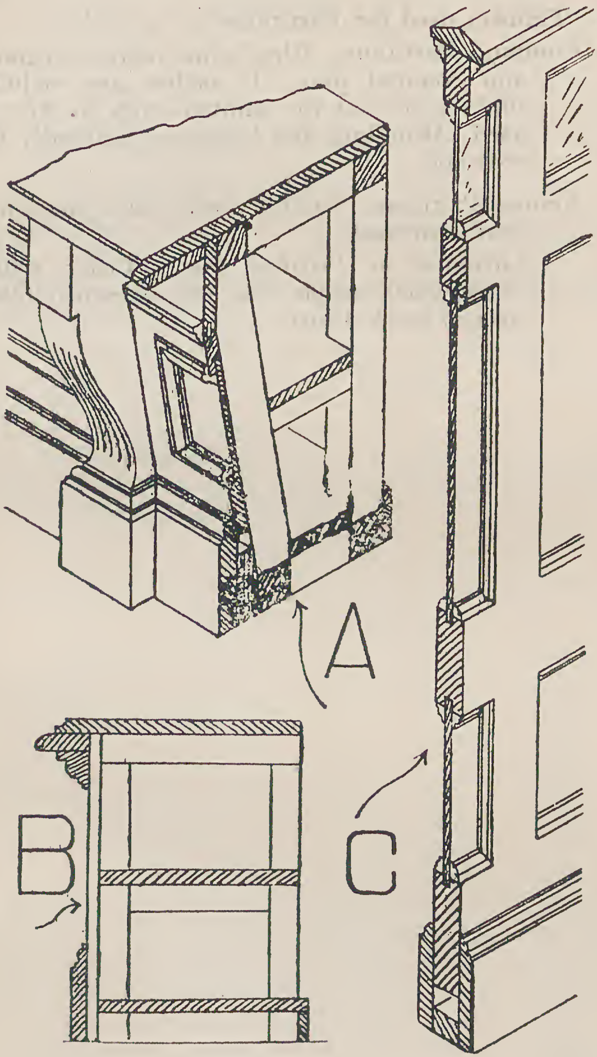


FIG. 112

with stout studs, the framed and panelled work being put in sections in between the studs.

587. Modern partitions are constructed with flush veneer

panels varying in thickness from ¼ in. to 13/16ths in. fixed to 3 in. x 2 in. oregon framings. Joints in the panels are usually made with a V joint.

588. Timbers used for Partitions are as follow:—

Common Partitions. Clear pine, baltic, oregon, kauri, and colonial pine. If sashes are included the timbers set out for painted work in Art. 549 are used. Moulding and beads are generally made of redwood.

Framed Partitions. *Painted work*: Baltic pine, clear pine, kauri, redwood.

Varnished or Polished Work: Cedar, Queensland maple, Pacific maple, silky oak, rosewood, blackwood, colonial beech, kauri.

CHAPTER IX

DESIGN AND CONSTRUCTION OF STEEL STANCHIONS AND TIMBER STORY POSTS

STEEL STANCHIONS

The steel for rolled sections should conform to S.A.A. Code A.1.

NOTATION.—The letters used in the various formula will have the following meanings respectively :—

S = Safe strength in lbs. per sq. in. of stanchion.
A = Area in sq. in. of the cross section.
I = Moment of Inertia of the section.
l = Length in feet of stanchion.
b & d = Dimensions of Section as indicated on sketches.
f = Safe strength in lbs. per sq. in. of steel in compression.
r = Least Radius of Gyration.

TABLE XXXI

Weights of Materials.

Brickwork	per cubic foot	120–140 lbs.
Concrete	„ „ „	130–150 „
Cement	„ „ „	90 „
Sandstone	„ „ „	130–150 „
Water	„ „ „	62·5 „
Timber (Softwood)	„ „ „	40 „
Timber (Hardwood)	„ „ „	70 „

589. Loads on Floors. The loads to be borne comprise the material in the walls and floors above them, and also the loads to be carried on the floors. The weight of the walls and floors is a matter easily determined, but that of the weight to be carried by the floors is a matter upon which there is some difference of opinion. Most of the text books give loads which are altogether too much for private houses and public buildings.

590. Table XXIV gives weight per sq. ft. for ordinary loading of floors in different kinds of buildings.

591. Loads on Stanchions. Fig. 113 is the plan of a floor supported by girders having stanchions under their centres. The shaded area, GHJK, shows the amount of floor and load to be supported by the stanchion M.

592. Safe Load per sq. in. on Steel. After deciding the load to be borne by the stanchions, the next step will be to fix upon the safe load per sq. inch for steel in compression. This will be the value of f in the formulae. Table XXXII gives the safe working loads per sq. inch that are to be put upon steel under varying conditions as provided for in S.A.A.—C.A.1. structural steel in buildings.

593. Short Columns. When the ratio of length to least cross sectional dimension is less than 4 to 1 the member is considered as a short column. It is allowed that such would fail in compression only and to find the weight bearing capacity it is only necessary to multiply the cross sectional area by compression strength of the steel per sq. inch.

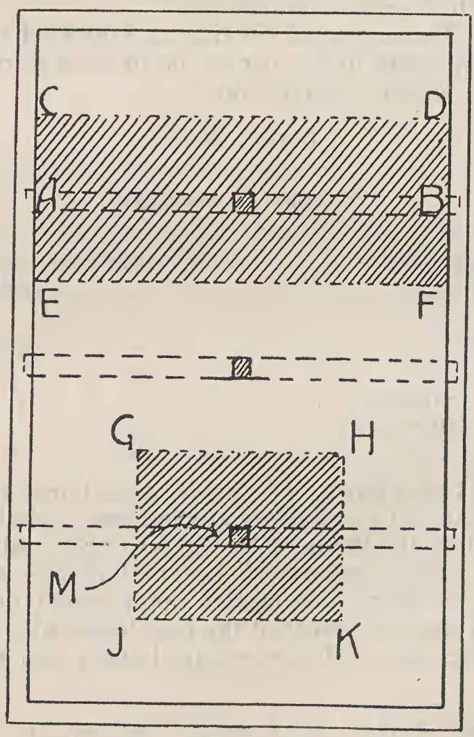


FIG. 113

594. Fixing Ends of Stanchions. The manner of fixing ends of the column has a bearing also in its strength. The terms "fixed ends" and "rounded ends" are hardly descriptive of the methods usually adopted for fixing the ends of columns or stanchions. It is difficult to fix the end of the column as would be understood by the description and sketches given in the usual text book. The best practice is to define the methods of fixing as "square bearing" and "pin bearing"; square bearing meaning well proportioned flanges giving the column a good square bearing at both bottom and top. Pin bearing would be exemplified by the case of a strut in a roof, in compression, and having each end fixed by a pin or bolt.

595. Formula. As shown in Art. 593, the allowable safe stress per sq. inch for a short column is the safe compression strength per sq. in. of the steel. For a long column this safe compression strength must be reduced by the formula

$$f = 18{,}000 - \left(80 \frac{l}{r}\right)$$

f = allowable safe stress per sq. inch which can be put on the section.
b = length of the column in inches.
r = the least radius of gyration.

This formula is applicable providing that:—

(a) The ratio $\frac{l}{r}$ does not exceed 150.
(b) The ends are fixed.
(c) The load is concentric.
(d) The value of f does not exceed 15,000 lbs. per sq. in.
(e) The length is not more than 50 times the least cross section dimension.

TABLE XXXII

	lbs. per sq. in.
Axial Tension:	
Structural Steel on Net Section	18,000
Rivets	9,000
Bending on Extreme Fibres:	
Tension	18,000
Compression	18,000
Shearing:	
Shop Rivets	13.500
Field Rivets	12,000
Bearing:	
Shop Rivets	22,500
Field Rivets	20.000

Stresses from S.A.A.—C.A.1.

596. Moment of Inertia. The determination of the value of the least radius of gyration for any particular section is somewhat tedious, but, nevertheless, must be understood, for it probably will be required to be undertaken in most cases. In determining this value it is necessary, first of all, to arrive at the *Moment of Inertia* of the cross section. It is not easy, in a few words, to give a definition either of the *Moment of Inertia* or the *Least Radius of Gyration.* For any particular section, the *Moment of Inertia* is the sum of the areas of all its individual parts multiplied by the squares of their respective distances from the neutral axis of the section.

A practical application of this to a rectangle is given by the formula:—

$$I = \frac{b\,d^3}{12}.$$

in which d = depth and b is the width, the neutral axis being taken in the direction parallel to the width.

The Moment of Inertia of a section may be obtained by multiplying the section modulus by d/2. The section modulus will be found described in the chapter on beams and girders.

The section modulus for a rectangular section Z is:— $\frac{b\,d^2}{6}$

Therefore:—

$$\frac{b\,d^2}{6} \times \frac{d}{2} = \frac{b\,d^3}{12}$$

which is the Moment of Inertia for a rectangular section as previously noted. The section modulus may be found graphically for all sections, and for a complicated section this will be found the easier method.

597. Least Radius of Gyration. By dividing the *Moment of Inertia* by the area of its section, the square of the *Radius of Gyration is obtained.* The reader is referred to the chapter on girders for more information as to Radius of Gyration.

Then

$$r^2 = \frac{I}{A} \text{ and } r = \sqrt{\frac{I}{A}}$$

To find the *least* Radius of Gyration it is necessary to find the Moment of Inertia about the neutral axis parallel to the longest dimension of the section.

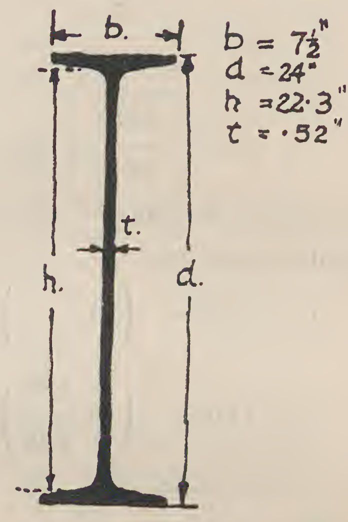


FIG. 114

For an I section, as shown by Fig. 114, taken about the neutral axis parallel to depth d, the formula becomes:—

$$I = \frac{d \times b^3}{12} + \frac{d \times t^3}{12} - \frac{h \times b^3}{12}$$

and

$$r = \sqrt{\frac{I}{A}}$$

598. Application of Formula. The formula given above may be applied as follows, to the case of a steel stanchion 15 feet long, and having a cross section, such as shown by Fig. 114.

Moment of Inertia of section =

$$\frac{24 \times 7{\cdot}5^3}{12} + \frac{22{\cdot}3 \times {\cdot}52^3}{12} - \frac{22{\cdot}3 \times 7{\cdot}5^3}{12}$$

$$= 62{\cdot}89.$$

The area of the section is 29·4 square inches. The least Radius of Gyration may therefore be obtained.

$$r = \sqrt{\frac{I}{A}}$$

$$= \sqrt{\frac{62{\cdot}89}{29{\cdot}4}}$$

$$= 1{\cdot}46.$$

Using the formula in Art. 595.

$$f = 18{,}000 - \left(80\ \frac{l}{r}\right)$$

$$f = 18{,}000 - \left(80\ \frac{180}{1{\cdot}46}\right)$$

$$= 8{,}136 \text{ lbs.}$$

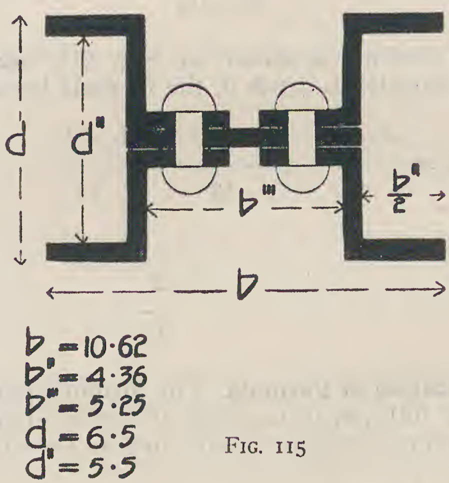


FIG. 115

To find the load this column will support, multiply f by the area. Therefore:—

$$f \times A = 8{,}136 \times 29{\cdot}4$$

$$= 107 \text{ tons.}$$

599. Z Box Stanchion. Fig. 115 is a section of a built stanchion 20 feet long, made from four Z bars riveted together with two rows of rivets. To find the load it will carry

$$H = \frac{bd^3 - (b'' d^{3''} + b''' d^3)}{12}$$

$$= \frac{10{\cdot}62 \times 6{\cdot}5^3 - (4{\cdot}36 \times 5{\cdot}5^3 + 5{\cdot}25 \times 6{\cdot}5^3)}{12}$$

$$= 62{\cdot}44$$

The area of section, minus the rivet holes, is 15·6 sq. inches, hence

$$r = \sqrt{\frac{62{\cdot}44}{15{\cdot}6}}$$

$$= 2$$

$$f = 18{,}000 - 80 \frac{l}{r}$$

$$= 18{,}000 - 80 \times \frac{240}{2}$$

$$= 8{,}400 \text{ lbs.}$$

$$\text{Load } W = f \times A$$

$$= 8{,}400 \times 15{\cdot}6$$

$$= 131{,}040 \text{ lbs.}$$

600. Construction of Stanchion. The rivets to hold the members of the stanchion together should be spaced at centres apart of not more than 16 times the thickness of the thinnest part joined. The holes for the rivets should be drilled and not punched, and portions to be joined should be drilled together, not separately, for, unless the greatest exactitude is attained when drilling each member separately, the holes will not coincide, and bad construction will result. Machine riveting is more effective than hand work, and as far as possible should be adopted.

601. Ends of Stanchions. It is a matter of the greatest importance that the ends of the stanchion should be quite square with the axis. To arrive at this result it is necessary to put the stanchion, after the members are riveted together,

in a lathe—the axis of lathe and stanchion exactly coinciding—and to turn the ends in a plane at right angles. The bearing surfaces of the top and bottom plates should be planed quite true in a planing machine, otherwise it is difficult to be certain of the ends of stanchion fitting well to them. A point which may exercise the mind of the designer is as to whether the vertical members of the stanchion are likely to be forced into the top and bottom plates. This is not likely to occur, for the section large enough to provide strength in the stanchion against bending under the load, will be found to have more than enough of bearing area, top and bottom, on plates to be quite safe against bearing stress—taking the safe bearing strength as 22,500 lbs. per sq. inch.

Care has to be taken to make the base plate sufficiently thick to prevent bending taking place towards the outer unsupported edges.

602. Sections of Stanchions. There is a great variety in the form of the sections for built stanchions. In the selection of the particular kind of section, four points of importance will require attention. First of all, the possibility of easily obtaining the particular section; next the amount of shop work required, such as drilling and riveting; then suitability of the section for the connection of girders to it; and, lastly, the opportunity which the section gives for bringing the bearing of the girder as near as possible to the axis of the column. A number of sections are used in American practice. Some of them are conspicuous by the number of rows of rivets required to connect the parts of the stanchion together. One of the most noticeable in having few rows of rivets is that of the Z section in which central plate and Z's are connected together by only two rows of rivets, whereas in some of the other sections there are as many as 10 rows. The sections most commonly used are I section steel joists, channel bars with either lattice bars or plates, and the Z bars made up (as shown in Fig. 115), or with the addition of plates on outside. The phœnix column made of bars, each having as section part of a circle, were also used, but have the disadvantage of a large number of rows of rivets. For small stanchions carrying light loads, a very useful section is formed of L's connected back to back and forming a cross section.

603. Eccentric Loading of Stanchions. It must be understood that eccentric loading of a column should, if possible, be avoided. Loads on one side only, especially in cases where the connection of the girder is at a distance, from the axis of the column are instances of eccentric loading.

The formula used is

$$\frac{W}{A} + \frac{M}{Z} = 18{,}000 - \left(80 \frac{l}{r} \right)$$

Where

W = The load, i.e., the Direct and Eccentric Loads.

A = Area of Section in sq. inches.

M = Moment due to the eccentricity.

Z = Section Modulus of Section.

An example of the application of the formula would be to find a suitable rolled steel section from a stanchion 10 ft. in height which has a direct load of 68 tons and an eccentric load of 5 tons 3 in. from the neutral axis.

$$\frac{W}{A} + \frac{M}{Z} = 18{,}000 - \left(80 \frac{l}{r} \right)$$

$$W = A \left[\left\{ 18{,}000 - \left(80 \frac{l}{r} \right) \right\} - \frac{M}{Z} \right]$$

Try a 10″ × 8″ × 55 lbs. R.S.J. where

A = 16·177 sq. ins.

Z about yy axis = 13·686

r „ „ „ = 1·840

M = 5 × 2,240 × 3 = 33,600 in. lbs.

Substituting in formula.

$$W = 16{\cdot}177 \left[\left\{ 18{,}000 - \left(80 \frac{120}{1{\cdot}840} \right) \right\} - \frac{33{,}600}{13{\cdot}686} \right]$$

$$= 167{,}051{\cdot}31 \text{ lbs.}$$

$$= 74{\cdot}58 \text{ tons.}$$

This will carry the load since the total load is 68 + 5 tons or 73 tons.

604. Fig. 116, which shows some bases and caps for stanchions, will illustrate the methods adopted to connect L's and gusset plates, the vertical portions of stanchion, with the end plates.

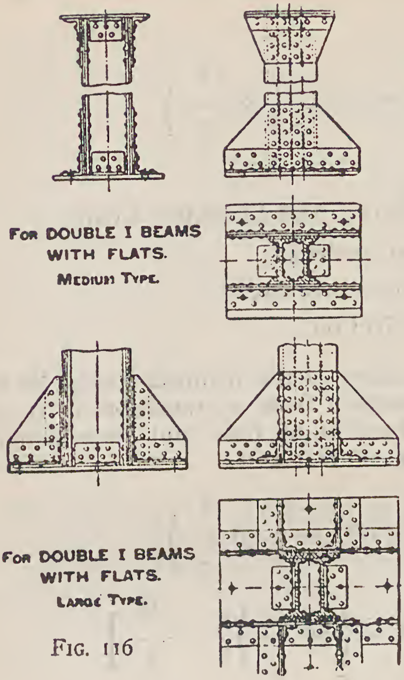


Fig. 116

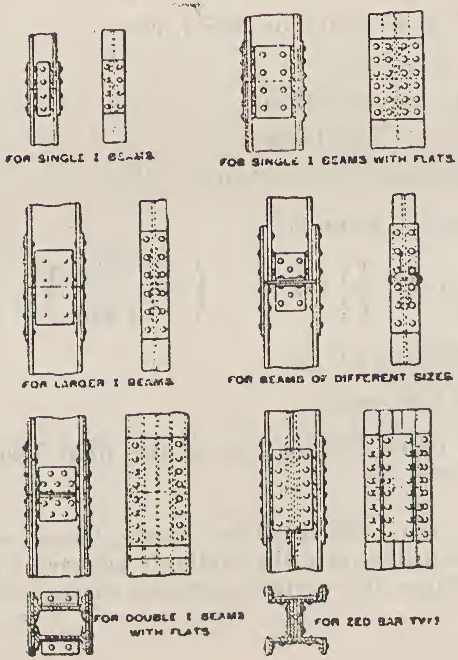


Fig. 117

In cases where stanchions are placed one above the other, it is best to make them continuous by joining them with side plates and rivets as shown by Fig. 117, rather than to fit each with a cap, after the style shown by Fig. 118. When made continuous, the butt joints and splice plates are put just above where the girders are connected to the sides with angle brackets or stools. These stools are easy to design. As will be obvious, the principal point to be attended to is to provide sufficient rivets at the joint with stanchion to prevent failure by shearing. For instance, in the case of a girder having a distributed load, it will be known

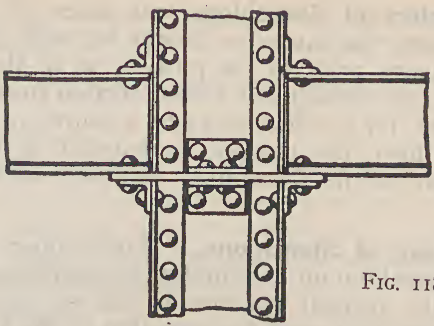


FIG. 118

that half of the weight of girder and load on it will be transmitted to the stanchion by means of the rivets which hold the stool. Taking the safe shear of steel rivets as 13,500 lbs. per sq. in., it will only be a matter of providing sufficient area of

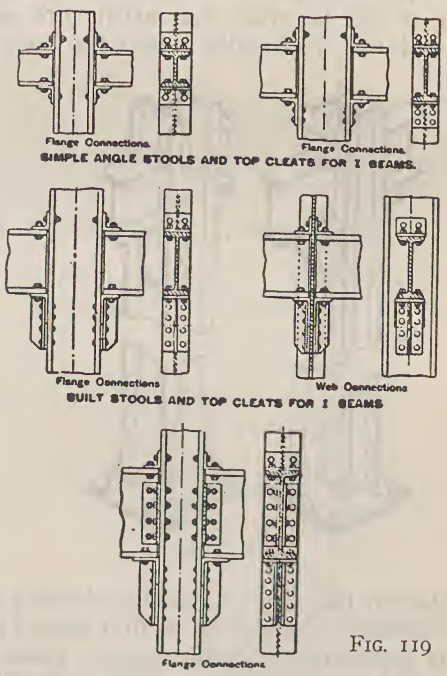


FIG. 119

rivets to withstand the shear due to half the girder and its load. It is usual to put top cleats on the girder as shown by the drawing in Fig. 119. Fig. 120 is a perspective view of the connections of girders to different sides of a Z stanchion.

605. Interiors of Stanchions. In cases of stanchions or closed sections, the interiors should be well painted with a good oxide paint prior to the putting on of the last plate or member. In this respect, the closed section presents one of its disadvantages, for it will always be a source of anxiety to the architect to have the interior so painted as to relieve him from all fear of its becoming oxidised, and consequently dangerous.

606. Setting of Stanchions. The proper setting of the column or stanchion on its template or bearing, and its placing in a perfectly vertical position is one of not the least important matters that need the attention of the architect. Some of these steel stanchions carry colossal loads, varying from a few to hundreds of tons—one instance at least is known of a column in a modern building carrying 1,700,000 lbs. When one remembers that the least divergence of the axis from the perpendicular will seriously lower the carrying efficiency of the stanchion, it will be clear that great care must be taken in setting a column, especially when its load is great. A

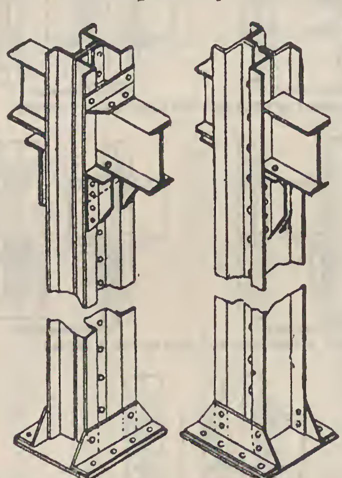


FIG. 120

method adopted in the case of columns having great weights to bear, is as follows: The column is first placed approximately upright on its foundation. Small wedges, about 3 in. long by $\frac{1}{2}$ in. wide, and $\frac{1}{4}$ in. at thickest portion, are then driven as required between the template and the under side of base. By means of these wedges, carefully driven, and a plumb line, the adjustment of the column to the perpendicular may be arrived at with the greatest nicety. Cement grout is then run

in under the base. Great care must be taken to see that the grout is forced to fill up all the space under the base.

TIMBER STORY POSTS

607. Notation:—

S = Safe strength of stanchion in lbs. per sq. inch.
A = Area in sq. inches of cross section.
l = Length of post in inches.
d = Least side or dimension of cross section.
f = Safe strength in lbs. per sq. inch of timber in compression.

608. Posts having a length not exceeding 12 times the least cross section dimension will fail in compression, and will not need the application of the formula. Those over that proportion are liable to fail by bending and their strength can only be determined by the following formula:—

$$S = \frac{A \times f}{1 + \dfrac{l^2}{1{,}100 \times d^2}}$$

The formula should be applied only to cases where the proportion of length to least cross dimension does not exceed 30.

609. The following is an example of the application of the formula:—

Find safe load for an oregon strut or post 6 feet long and 5 inches by 6 inches in cross section.

$$A = 5 \times 6 = 30 \text{ sq. inches}$$
$$l = 6 \text{ feet} = 72 \text{ inches}$$
$$f = \frac{7{,}125^*}{5} = 1{,}425 \text{ lb.}$$
$$d = 5 \text{ inches}$$

Then:

$$S = \frac{30 \times 1{,}425}{1 + \dfrac{72^2}{1{,}100 \times 5^2}}$$
$$= 16 \text{ tons.}$$

Tables XXXIII to XXXVII, inclusive, give safe loads for different kinds of timber used as columns.

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* Ultimate strength of Oregon in compression from Table XXIII, page 168.

TABLE XXXIII

Safe Loads in Tons for Oregon Columns or Struts of Small Cross Sections Both Ends to be Square Bearing.

Cross Section in Inches	Length in Inches									
	36	42	48	54	60	66	72	78	84	90
5 x 6	..	..	..	..	..	16·5	16·0	15·6	15·2	14·7
5 x 5	..	..	..	..	..	10·9	13·4	13·0	12·6	12·3
4 x 5	..	..	..	10·9	10·6	10·2	9·8	9·4	9·1	8·7
4 x 4	..	..	..	8·7	8·4	8·2	7·9	7·6	7·3	7·0
3 x 4	..	6·5	6·2	5·9	5·6	5·3	5·0	4·7	4·5	4·2
3 x 3	..	4·9	4·6	4·4	4·2	4·0	3·7	3·5	3·3	3·1
2 x 3	2·9	2·7	2·5	2·3	..	..	..	..	..	..

Cross Section in Inches	96	102	108	114	120	126	132	138	144
5 x 6	14·3	13·8	13·4	13·0	12·5	12·1	11·7	11·3	10·9
5 x 5	11·9	11·5	11·2	10·8	10·4	10·1	9·7	9·4	9·1
4 x 5	8·3	8·0	7·6	7·3	7·0	..	..	..	..
4 x 4	6·7	6·4	6·1	5·8	5·6	..	..	..	..
3 x 4	..	..	..	..	..	..	..	..	..
3 x 3	..	..	..	..	..	..	..	..	..
2 x 3	..	..	..	..	..	..	..	..	..

TABLE XXXIV

Safe Loads in Tons for Oregon Columns, having Square Bearings each end.

Size of Column in Inches	Sec. Area of Column in Sq. Inches	Length of Column in Feet												
		8	9	10	11	12	13	14	15	16	17	18	19	20
6 x 6	36	18·58	17·69	16·79	15·90	..	..	..	..	..	..	..	..	..
8 x 8	64	36·00	34·92	33·80	32·63	31·45	..	..	..	..	..	..	..	..
9 x 9	81	46·70	45·56	44·36	43·10	41·80	40·47	39·13	..	..	..	..	..	..
10 x 10	100	58·69	57·51	56·25	54·91	53·52	52·09	50·62	49·14	47·65	..	..	..	..
12 x 12	144	..	..	83·97	82·54	81·00	79·45	77·75	76·05	74·31	72·70	70·60	69·0	67·2
14 x 14	196	..	..	..	115·36	113·74	112·04	110·25	108·40	106·50	104·51	102·50	100·5	98·4
16 x 16	256	..	..	..	153·40	151·70	149·9	148·0	146·0	144·0	141·9	139·7	137·5	135·2
18 x 18	324	..	..	..	196·50	194·80	192·9	191·0	188·9	186·8	184·6	182·2	179·9	177·4

TABLE XXXV

Safe Loads in Tons for Iron Bark Columns, having Square Bearings each end.

Size of Column in Inches	Area of Column in Sq. Inches	Length of Column in Feet												
		8	9	10	11	12	13	14	15	16	17	18	19	20
6 x 6	36	32·59	31·03	29·46	27·9	..	..	..	..	..	..	..	..	..
8 x 8	64	63·16	61·28	59·30	57·25	55·17	..	..	..	..	..	..	..	..
9 x 9	81	81·92	79·93	77·82	75·61	75·33	71·00	68·65	..	..	..	..	..	..
10 x 10	100	102·97	100·90	98·6	96·33	93·90	91·38	88·81	86·21	83·59	..	..	..	..
12 x 12	144	..	..	147·32	144·78	142·11	139·39	136·41	133·42	130·37	127·17	124·14	121·0	117·8
14 x 14	196	..	..	..	202·39	199·55	196·56	193·43	190·16	186·80	183·35	179·83	176·2	172·6
16 x 16	256	..	..	..	269·1	266·1	263·0	259·7	256·2	252·6	248·9	245·1	241·2	237·2
18 x 18	324	..	..	..	344·7	341·7	338·5	335·1	331·5	327·7	323·79	319·74	315·6	311·3

TABLE XXXVI

Safe Loads in Tons for Tallow-Wood Columns, having Square Bearings each end.

Size of Column in Inches	Sec. Area of Column in Sq. Inches	Length of Column in Feet												
		8	9	10	11	12	13	14	15	16	17	18	19	20
6 x 6	36	24·71	23·53	22·35	21·31	..	..	..	..	..	..	..	..	..
8 x 8	64	47·90	46·47	44·97	43·42	41·84	..	..	..	..	..	..	..	..
9 x 9	81	62·13	60·70	59·02	57·34	55·61	53·85	52·06	..	..	..	..	..	..
10 x 10	100	78·09	76·52	74·84	73·06	71·21	69·31	67·4	65·38	63·39	..	..	..	..
12 x 12	144	..	..	111·71	109·80	107·77	105·65	103·50	101·18	98·87	96·52	94·15	91·8	89·4
14 x 14	196	..	..	..	153·48	151·34	149·03	146·69	144·22	141·67	139·1	136·38	133·8	130·9
16 x 16	256	..	..	..	204·1	201·8	199·4	196·9	194·3	191·6	188·8	185·9	182·9	179·9
18 x 18	324	..	..	..	261·46	259·16	256·71	254·12	251·39	248·53	245·56	242·55	239·3	236·1

TABLE XXXVII

Safe Load in Tons for Jarrah Columns, having Square Bearings each end.

Size of Column in Inches	Sec. Area of Column in Sq. Inches	Length of Column in Feet												
		8	9	10	11	12	13	14	15	16	17	18	19	20
6 x 6	36	22·81	21·72	20·62	19·50	..	..	..	..	..	..	..	..	..
8 x 8	64	44·21	42·89	41·50	40·08	38·62	37·1	..	..	..	..	..	..	..
9 x 9	81	57·34	55·95	54·47	52·93	51·33	49·75	48·07	..	..	..	..	..	..
10 x 10	100	72·08	70·63	69·08	67·44	65·73	63·97	62·17	60·35	58·51	..	..	..	..
12 x 12	144	..	..	103·12	101·3	99·47	97·51	95·48	93·39	91·23	89·09	86·9	84·7	82·5
14 x 14	196	..	..	..	141·67	139·70	137·59	135·39	133·12	130·76	128·38	125·88	123·4	120·8
16 x 16	256	..	..	..	188·3	186·3	184·1	181·8	179·4	176·8	174·2	171·6	168·8	166·0
18 x 18	324	..	..	..	241·32	239·20	236·9	234·55	232·03	229·39	226·65	223·82	220·9	217·9

CHAPTER X

DESIGN OF BEAMS AND GIRDERS

SHEARING STRESSES

610. Principle of Shearing. The tendency of the fibres of a solid timber team or the component parts of a steel girder to slide upon each other horizontally may be demonstrated by placing some planks of equal length upon each other, the whole being supported as a single girder and loaded as shown by upper diagram, Fig. 121. Provided that the load is sufficient to make the planks deflect to a noticeable extent, it will be found that the ends which originally coincided are no longer coincident, but project beyond each other, as shown by the central diagram, Fig. 121. This displacement at the ends will

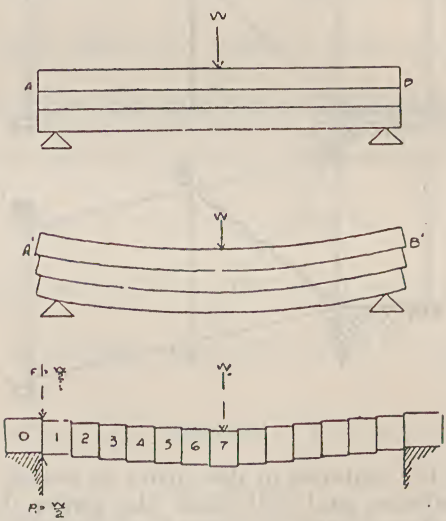


FIG. 121

be due to the sliding of the adjacent surfaces of the planks upon each other. Were the beam a single one instead of being composed of planks, there would still be a tendency to slide, and were the fibres not strong enough to resist the sliding tendency there would be a longitudinal crack as the result. As a matter of fact, timber beams very often fail under this

shearing stress, as it is called. It is the same stress that tends to shear the rivets which connect the L's of a girder to the web or flanges.

611. In addition to these horizontal shearing stresses, there are vertical shearing stresses of equal magnitude tending to shear the beam or girder in vertical planes illustrated by the lower diagram in Fig. 121. This diagram represents a girder supported at both ends and loaded with a load W at centre. The shear occurs, owing to a want of balance in the forces, acting on the girder. The piers each have to exert a reaction equal to $\frac{W}{2}$ — that is to say, each end of the girder will bear half the load on to a pier; this load or force is indicated by F. This force is balanced exactly by R. There is then a third force W,

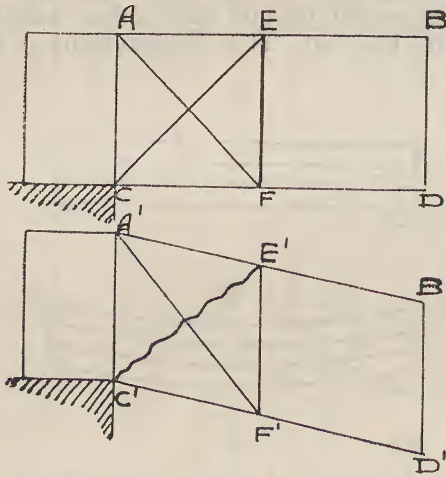


Fig. 122

which, unless the material of the girder be strong enough, will be without balance, and will shear the girder down through two vertical planes, either at the faces of piers or at other places. The shear obviously through either of the two vertical planes will be ½ W, or $\frac{W}{2}$. This force, it will be found, is equal to the reaction force R. Briefly then, it may be stated that the vertical shear at face of any bearing will be equal to the reaction at that pier.

Forces in diagonal directions are resultant from the horizontal and vertical shearing stresses. Fig. 122 shows one end of a beam and its support. A square A E F C is marked on the side of the girder in the upper diagram. When the girder is deflected owing to action of load, the square is turned into a shape like a rhombus, so that the diagonals A F and E C are altered in length. In the lower diagram this rhombus, owing to deflection of the girder, is shown. It will be noticed that the diagonal A' F' is longer, and E' G' shorter, than before the deflection. It can be demonstrated that these diagonal forces are equal in intensity to the horizontal and vertical shearing stresses which produce them. The diagonal forces of compression E' C' tend to buckle webs of steel girders, while those of tension A' F' tend to tear concrete beams. These forces need to be adequately resisted.

BENDING MOMENTS

612. Reactions and Bending Moments. The Fig. 123 is a diagram of a girder A B, having a load W and span L. The reactions are each equal to $\frac{W}{2}$ since W is at the centre O. It may be assumed that the centre of the girder O is fixed by W, and that the forces of reaction R and R' tend to bend the girder upwards about the point O. Each reaction force will have the advantage of a leverage equal to ½ of L, or $\frac{L}{2}$ in making its effect at O. The effect at O will be one of the reactions (R' for example) multiplied by its leverage, $\frac{L}{2}$. That is to say, the effect of R' about O will be $R' \times \frac{L}{2}$, or since $R' = \frac{W}{2}$, the effect will be $\frac{W}{2} \times \frac{L}{2}$, which is $= \frac{WL}{4}$. This effect is called the moment of the reaction about O, or more generally the bending moment of the load W. Either reaction may be taken to obtain the bending moment, and one is sufficient. In the equations which follow the term bending moment will be abbreviated to B M. The B M will be either inch lbs., or inch tons, according to units of length and weight used.

613. Formulae for Bending Moment and Shearing Stresses. The bending moment is the force or forces which tend to bend or break a beam. The formulae which follow give the maximum B M in each case. It is, however, at times very desirable to know the bending moment at other places than the

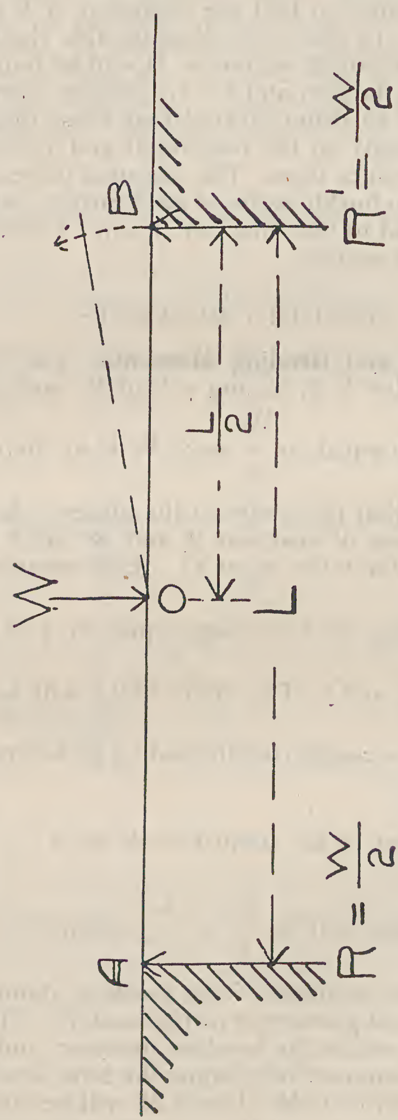


Fig. 123

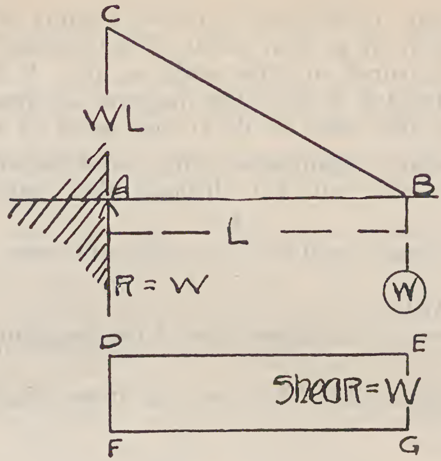


FIG. 124

maximum point. The B M at any other place than the maximum can, of course, be calculated, but it is by far the most convenient to obtain such by means of a graphic construction called the diagram of bending moments. The shape of diagram for each kind of loading will be referred to when describing the bending moments for these loadings. Figs. 124 to 129 inclusive are diagrams showing various positions and kinds of loads on cantilevers and beams. Fig. 124 shows a cantilever with a load W and projection of L. The reaction here will be W and leverage L, so that max. B M = W L. The diagram of B M's will be obtained by setting up max. B M to any scale at A C. Then a triangle having A C as one side and the projection L as a base will be the diagram. A vertical line

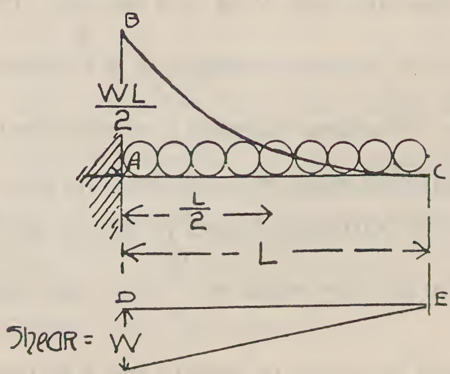


FIG. 125

from any point on cantilever to meet sloping side of triangle will give the B M at that point. The vertical line must, of course, be measured to same scale as max. B M was set to. The rectangle D E F G is the diagram of shearing stresses. The shear in this case = W at any point of the cantilever.

Fig. 125 shows a cantilever with a distributed load. In the example the load will act through the centre of gravity, hence the leverage will be $\frac{L}{2}$ so that the max. B M will be $W \times \frac{L}{2} = \frac{WL}{2}$. The upper side of the diagram of B M's will be half of a parabola. The shearing stress diagram will be a triangle.

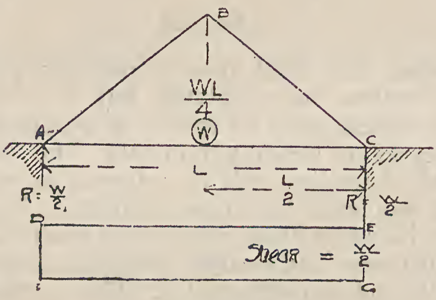


Fig. 126

Fig. 126 illustrates a beam with a central load when as before described the max B M will be $\frac{WL}{4}$. The diagram of BM's will be an isosceles triangle A B C having its altitude equal to $\frac{WL}{4}$. The shear diagram is a rectangle D E F G, with vertical dimensions equal to reactions R or R'.

A beam with distributed load is shown by Fig. 127. The reactions here are also equal to $\frac{W}{2}$, but each half of the load acting through its centre of gravity has a leverage of only $\frac{L}{4}$.

Therefore max. B M $= \frac{W}{2} \times \frac{L}{4} = \frac{WL}{8}$. The diagram of bending moments is a parabola having a height of max. B M *i.e.*, $\frac{WL}{8}$. The method of drawing half of the parabola is indicated on this drawing. Briefly, it consists of drawing a horizontal line from the top of the max. B M line to intersect a vertical line from the face of pier. The latter line and the half span are each divided into the same number of equal parts. Vertical lines are drawn from the points of division of the half span and lines are also drawn from points on vertical line to point B. The intersections of these lines will give, as shown by the drawing, points in the curve of the parabola. For this example of loading the shear diagram is composed of two triangles, only one of which need be drawn.

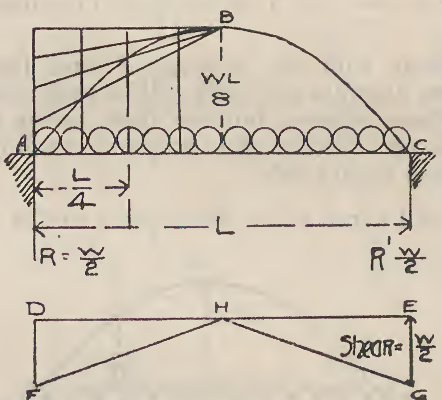


FIG. 127

614. Fig. 128 is an interesting case, being one where the load is concentrated, but not central. Here the reactions R and R′ are not equal. The reactions are respectively portions of W, which bear to each other the same proportion that the lengths Z and Y of the span L are to each other. The proportion of R will be found by dividing the load W by the span to ascertain the load per foot and multiplying this by the length of Z. The reaction at R will therefore be $\frac{WZ}{L}$. The leverage of this reaction will be the length of Y. Consequently the max.

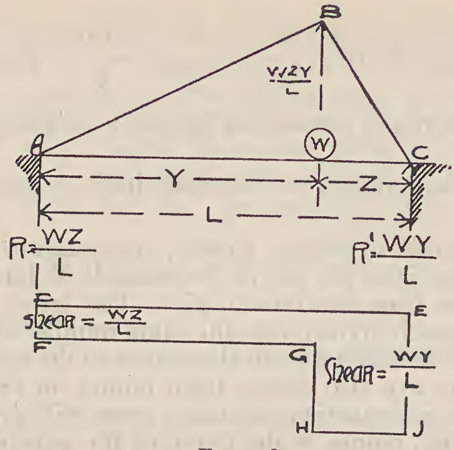


FIG. 128

B M will be $= \dfrac{WZ}{L} \times Y = \dfrac{WZY}{L}$. The other reaction R′ could be taken with its leverage Z and the same result obtained. The diagram of B M's will be understood from what has already been written, but the shear stress diagram needs a word. It is composed of two rectangles, each equal in height to the reaction on its side.

Fig. 129 will serve as an illustration of the cases where a

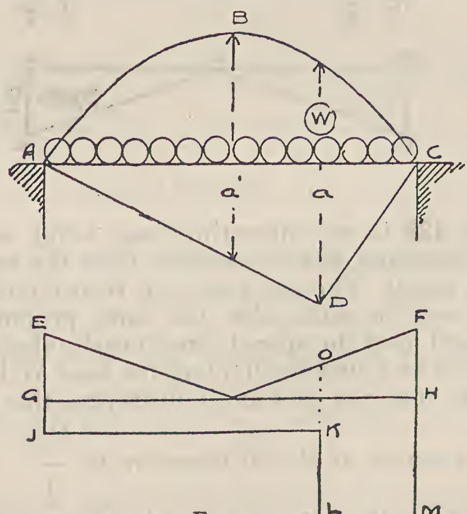


FIG. 129

girder has more than one kind of load. In the example a distributed load and eccentric concentrated load are combined. It will be seen that max. B M for each load is obtained and the diagrams of B M's formed base to base. A perpendicular through both at any point will give the total B M at that place. The shear diagrams are also combined in the same way.

The foregoing is a brief description of the effects due to the external forces of the loads and reactions. These forces are the forces tending to destroy the beam or girder. It now

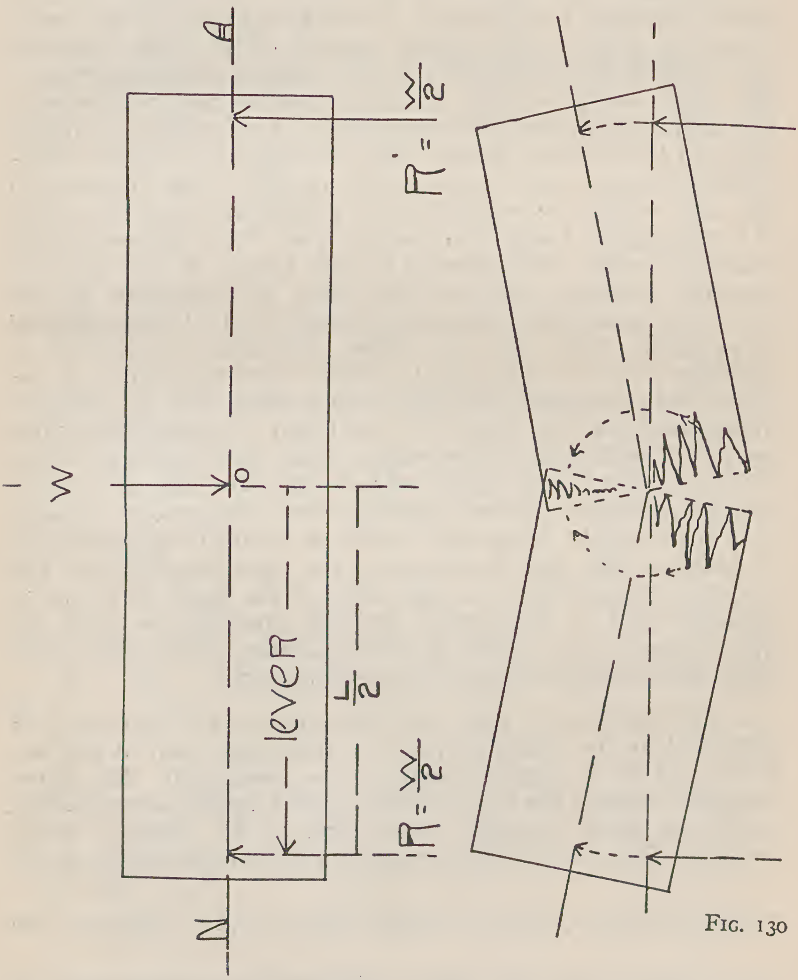


FIG. 130

becomes necessary to investigate the forces belonging to the girder which are brought into action to resist this tendency towards destruction.

MOMENTS OF RESISTANCE

615. Moments of Resistance. Fig. 130 shows two views of a rectangular beam with a load W, and reaction of R and R′. The lower view shows the beam in collapse turning about the point O at the centre. The fibres above the neutral axis are in compression, those below are in tension. The dotted circular arrows indicate the direction of the two halves of the beam about the point O due to the turning effect of the external forces W, R, R′. The fibres at this central vertical section of the beam must be able, by their tension and compression strength, and by their leverages about O, to resist the turning effect of the external forces. The investigation of their ability in this direction may be studied by the aid of the diagrams in Fig. 131, which are respectively a section and portion of side of a rectangular beam. On the side view the compression and tension stresses are indicated by the arrows R and Q. The internal resisting forces of the beam are indicated by the arrows of gradually increasing length from O upwards and downwards. They are, of course, indicated as opposite in direction to arrows R and Q. These internal forces of the fibres have unequal leverages since they are at different distances from the centre of the beam. Consequently they are not of equal value in resistance when their moments about N A are taken. As a matter of fact, they are only of value in direct proportion to their distance from the centre. A layer X Y for example, being half way from centre to upper surface of beam is only half so strong as the upper layer O R. The graphic representation on the value of the layer X Y can be obtained as U V by cutting off with lines drawn from the upper layer to the centre S of the section. The value of all other layers may be shown in the same way.

It will therefore be clear that the values of the fibres may be indicated by the triangle O R S, in the upper half of the sections, and by an equal triangle in the lower half. The upper triangle contains the area of fibres useful against compression, while the lower triangle shows area of the fibres to resist tension. The area of either triangle will be obtained by multiplying the base by half the height, that is $b \times \frac{d}{4} = \frac{b\,d}{4}$. The force value of this area may be obtained by multiplying it by

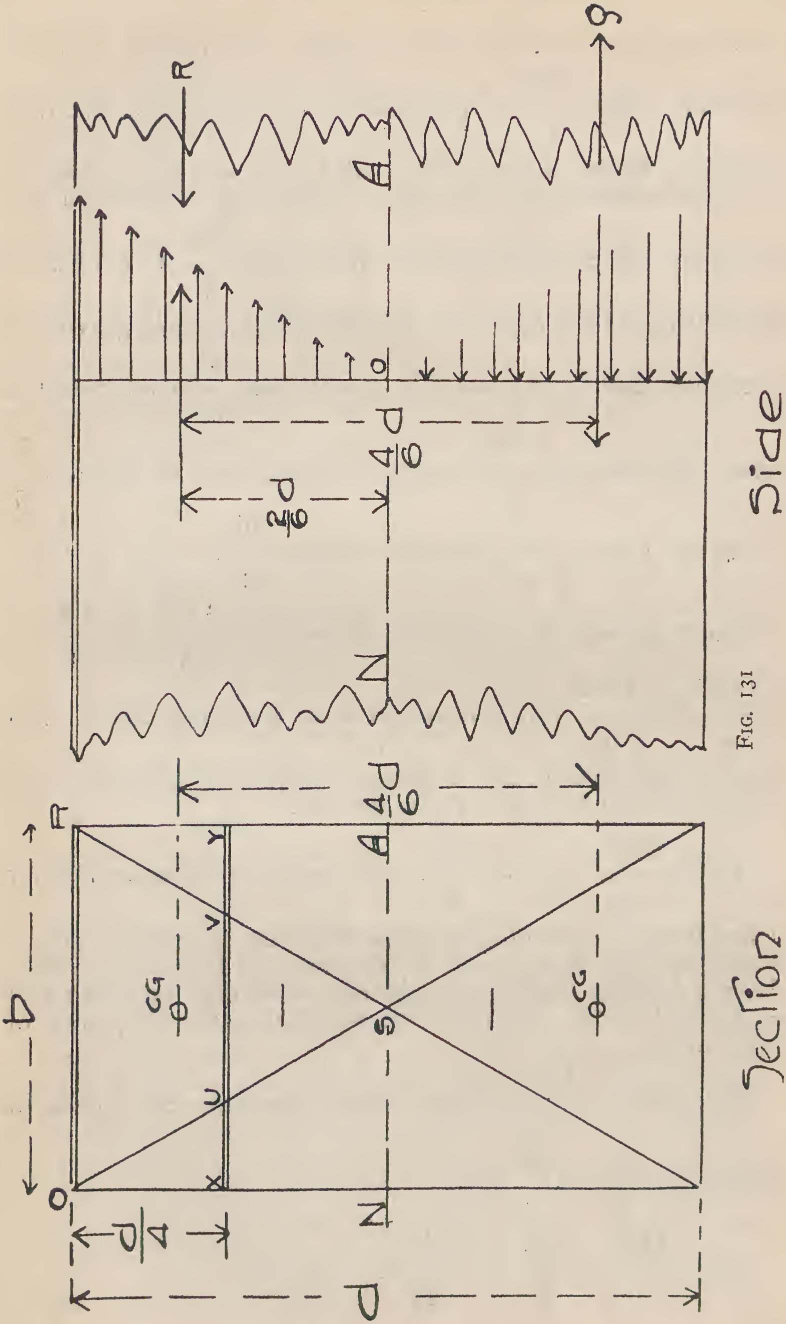


FIG. 131

the co-efficient of transverse strength. Let f equal this co-efficient. Then $\frac{f\,b\,d}{4}$ = the value of the fibres in a direction along the beam. But this force will have a leverage about the N A, or neutral axis of section. The group of fibres in the triangle O R S represented by the value $\frac{f\,b\,d}{4}$ will act in a line through their centre of gravity. The centre of gravity of a triangle will be at a point on the altitude $\frac{2}{3}$ down from the apex. This distance $\frac{2}{3}$ of height of triangle will be equal to $\frac{2}{6}$ of depth of beam, which may be written $\frac{2d}{6}$.

The force value of fibres $\times$ leverage $= \frac{f\,b\,d}{4} \times \frac{2\,d}{6} = \frac{2\,f\,b\,d^2}{24}$, or $\frac{f\,b\,d^2}{12}$, which is the M R of the upper fibres. The lower triangle will have a similar moment of resistance, and must be added to that of the upper one.

Hence $\frac{f\,b\,d^2}{12} \times 2 = \frac{f\,b\,d^2}{6}$. The forces of upper and lower triangle are equal and have combined effect to produce motion round the centre line or N A of section of beam, hence they form a "couple," in which case one force may be taken and multiplied by the distance between the centre of gravity of both forces.

One force $= \frac{f\,b\,d}{4}$ and the distance between the centres of gravity of both is $\frac{4}{6}$ of d.

Then $\frac{f\,b\,d}{4} \times \frac{4\,d}{6} = \frac{4\,f\,b\,d^2}{24}$.

By cancellation we obtain $\frac{f\,b\,d^2}{6}$, a similar result to that obtained by taking each triangle separately.

616. Section Modulus. By omitting f from the expression we obtain the value $\frac{b\,d^2}{6}$ which is called the Section Modulus.

The section modulus for any cross section may be determined graphically as follows:—

The hollow square MNDC, Fig. 132, represents the cross section of a box girder. The centre of gravity of the section will be the centre O of the whole section. The neutral axis N A passes through the centre of gravity. Lines drawn from the corners C and D to the centre O will cut the line P Q in the points E and B. The space E B D C will indicate the effective area of the top portion P Q D C of the section. The effective areas of sides of the section must now be found. Take the half 1 2 Q B of the right hand side. By projecting the lines of the sides up to the top of the section, and then drawing lines from these projected points on the top line to the centre O, a space OAB will be obtained, which will be the effective area of the half 1 2 Q B of the right hand side of the section. The other side may be determined in the same way. The effective area of the upper half of the whole section is thus found. This effective area is darkened by close ruled lines on the drawing. The centre of gravity CG, of the figure, representing the effective area, must next be found. If the weight of the effective area shape be divided by the weight of one sq. inch, the result will give the number of sq. inches in the effective area. The number of sq. inches of effective area, multiplied by the leverage d' will give the section modulus, and if the section modulus be multiplied by f, the safe strength of the material, the safe moment of resistance will be found.

In the lower portion of Fig. 132 a cross section of a hollow circular shape is given. The effective area and section modulus is obtained on the same principle as described above. Lines are drawn touching the top and bottom of the section. The top one is marked EF. Each point in the outline of the effective area shape is obtained as that marked C. First a point is taken on the outline of the cross section. Let point A be an example. A vertical projector is drawn from this point to give B on EF. A line is then drawn from B to the centre O of the section. This latter line cuts a line from A, parallel to NA,

and gives C one of the points in the outline of the effective area. A large number of points are so taken, and from these the outline of the complete shape of one half of the effective

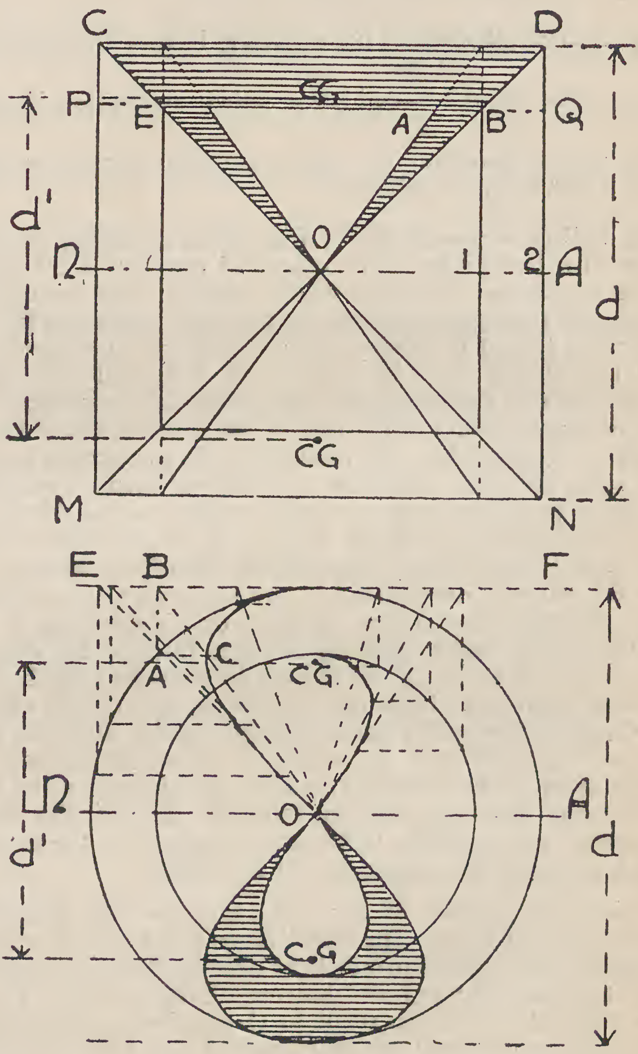


FIG. 132

area determined. The centre of gravity, distance d$'$, and area are then found just as in the case of the square, and with these data the section modulus, and if necessary the moment of re-

sistance will be determined. Any shape of cross section may be so treated on the same principle.

The section modulus multiplied by half the depth of section gives for a rectangle—

$$\frac{bd^2}{6} \times \frac{d}{2} = \frac{bd^3}{12}$$

which is the Moment of Inertia of the section of a rectangle. Conversely it follows that the Moment of Inertia multiplied by f and divided by $\frac{d}{2}$ gives the Moment of Resistance of the section as:—

$$f \times \frac{bd^3}{12} \div \frac{d}{2} = \frac{fbd^2}{6}$$

$$\text{or } \frac{fI}{\frac{d}{2}} = MR$$

in which I equals Moment of Inertia.

This leads to another very important matter which it is proper should be touched on here.

Suppose that all the fibres of the section were made into two *very* thin layers, each of which accordingly would be $\frac{A}{2}$. These layers, which of course would be very wide, could be placed one on each side of the neutral axis, and at a distance therefrom of r on each side. If the stress on extreme top and bottom fibres of original section be represented by f, the proportionate value of the fibres in the thin section would be $\frac{fr}{\frac{d}{2}}$

and the Moment of Resistance of these thin layers would be—

$$2 \times \frac{A}{2} \times \frac{fr}{\frac{d}{2}} \times r, \text{ or } \frac{Afr^2}{\frac{d}{2}}$$

Now r could be at any distance, and the Moment of Resistance would vary accordingly, but it might be such that the Moment of Resistance of the layers would be just the same as the Moment of Resistance of the original section.

$$\text{or } \frac{Afr^2}{\frac{d}{2}} = \frac{fbd^2}{6}$$

Instead, however, of putting the Moment of Resistance in the form of $\frac{fbd^2}{6}$ we may write it $\frac{fI}{\frac{d}{2}}$ in which way the equation would appear—

$$\frac{Afr^2}{\frac{d}{2}} = \frac{fI}{\frac{d}{2}}$$

This simplified $= Ar^2 = I$.

From this we find that—

$$r^2 = \frac{I}{A}$$

$$\text{and } r = \sqrt{\frac{I}{A}}$$

This particular length of r is called the Radius of Gyration. Obviously it will be less in length for any section where d is the least dimension of cross section, for such a case it is called the least Radius of Gyration. It is a dimension, of importance in determining the strength of columns, as will be seen by a study of chapter IX.

617. Application of Formula to Timber Beams. The coefficient f of transverse strength, called also the modulus of rupture is obtained by experiment on beams loaded transversely; when, knowing the breaking load, the span and breadth and depth of the beam, the value f can be found. It may, however, be stated that to be exact the proportions of the experimental beam in depth and breadth should be in the same ratio as the beam to which the value f is to be applied.

The difference, however, is not great, and the error is generally neglected.

By equating the bending moment and moment of resistance some very useful formulae may be obtained.

Since B M = M R it follows that for a beam loaded at centre, the equation will be $\frac{WL}{4} = \frac{f\,b\,d^2}{6}$, and that

$$W = \frac{f\,b\,d^2}{6} \div \frac{L}{4} = \frac{f\,b\,d^2}{6} \times \frac{4}{L} = \frac{2\,f\,b\,d^2}{3\,L},$$

also that $f = \frac{WL}{4} \div \frac{b\,d^2}{6} = \frac{WL}{4} \times \frac{6}{b\,d^2} = \frac{3\,W\,L}{2\,b\,d^2}$.

The formulae may now be applied to the case of a timber beam with a central load.

Let L = span = 15 ft. or 180 in.

Let W = 8 tons of 17,920 lbs.

Let f = 4,000 lbs. safe load for ironbark.

Let d = 12 in.

Assume that breadth is not known and that it is required to find it.

Then since $\frac{f\,b\,d^2}{6} = \frac{WL}{4}$

$$b \times \frac{f\,d^2}{6} = \frac{WL}{4}$$

$$b = \frac{WL}{4} \div \frac{f\,d^2}{6}$$

$$b = \frac{WL}{4} \times \frac{6}{f\,d^2} = \frac{6\,WL}{4\,f\,d^2} = \frac{3\,WL}{2\,f\,d^2}$$

$$b = \frac{3 \times 17{,}920 \times 180}{2 \times 4{,}000 \times 144} = 8{\cdot}4''$$

In the same way it may be shown that d will be 12 in. in the above example when b = 8·4 in.

Thus—

$$d^2 \times \frac{f\,b}{6} = \frac{WL}{4}.$$

$$d^2 = \frac{WL}{4} \div \frac{f\,b}{6}$$

$$d^2 = \frac{6\,WL}{4\,f\,b} = \frac{3\,WL}{2\,f\,b}$$

$$= \frac{3 \times 17{,}920 \times 180}{2 \times 4{,}000 \times 8{\cdot}4} = 144 \text{ sq. ins.}$$

$$d = \sqrt{144} = 12''$$

We may have span depth and breadth and require to find the load that the beam will carry.

The formula will be—

$$\frac{WL}{4} = \frac{f\,b\,d^2}{6}$$

$$W \times \frac{L}{4} = \frac{f\,b\,d^2}{6}$$

$$W = \frac{f\,b\,d^2}{6} \div \frac{L}{4}$$

$$W = \frac{4\,f\,b\,d^2}{6\,L} = \frac{2\,f\,b\,d^2}{3\,L}.$$

Assuming same data as before the working will be—

$$W = \frac{2 \times 4{,}000 \times 84 \times 144}{3 \times 180}$$

$$= 17{,}920 \text{ lbs.}$$

The resistance of the beam to shear may now be ascertained.

$$\text{The total shear} = \frac{W}{2} = \frac{17{,}920}{2} = 8{,}960 \text{ lbs.}$$

The depth of the beam is one foot. Hence the shear per foot vertical and horizontal will be

$$\frac{8{,}960}{1} = 8{,}960 \text{ lbs.}$$

A layer of the beam 1 foot long will have a cross section area of 12 in. x 8·4 in. = 100·8 sq. in. Ironbark will stand a safe shear of 500 lbs. per square inch. Then 100·8 sq. in. × 500 lbs. = 50,400 lbs., so that the beam will stand 50,400 lbs. for every foot run, whilst it only *has* to stand a shear of 8,960 lbs. per foot. It can be demonstrated that the strength of a beam increases as the square of the depth, but only directly as the breadth. It follows then that it is desirable to have as much depth as possible. In large timber beams it is not always possible to get sufficient depth in one piece of timber, and it may be necessary to put one piece on top of the other. If the pieces so placed be not rigidly connected they will have no more strength together than twice the strength of one. This is because they will slide owing to the horizontal shearing stress along the joint of the two. If blocks be inserted along this joint plane to project into both timbers and so prevent them sliding, the beam can be calculated as a solid piece of timber. These blocks must be designed to resist the horizontal shearing stress.

Fig. 133 shows sections and portions of two 12 in. x 12 in. beams, one on top of the other. It is required to find the

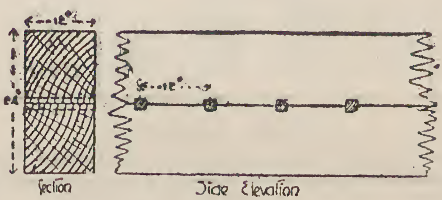


FIG. 133

number of 2 in. x 2 in. ironbark shear blocks which will be required along the joint of the two beams, so that the combination may be treated as a single girder.

Let it be supposed that the load on the girder is 48,000 lbs. distributed. The total shear will be

$$\frac{W}{2} = \frac{48{,}000}{2} = 24{,}000 \text{ lbs.}$$

The shear per foot will be

$$\frac{24{,}000 \text{ lbs.}}{2 \text{ feet}} = 12{,}000 \text{ lbs.}$$

Each block has an area of 12 in. x 2 in. = 24 sq. in.
Ironbark will stand safe shear of 500 lbs. per square inch.
The 24 sq. in. x 500 = 12,000 lbs.

Therefore, since the shear per foot is 12,000 lbs., one block per foot is required. It must not be forgotten, however, that the cutting of the blocks will reduce the effective area of the section of the beam, so that the beam will not be quite as strong as a beam 24 inches deep.

618. Tables giving Safe Loads for Timber Beams. Tables XXXVIII to XLI give safe loads for timber beams of various kinds and sizes:—

TABLE XXXVIII

Safe Distributed Loads in Tons for Tallow-Wood Beams of Varying Spans.

Cross Section in Inches	Span in Feet							
	10	12	14	16	18	20	22	24
9 x 8	12·258	10·215	..	..	..	..	..	..
9 x 9	13·790	11·492	..	..	..	..	..	..
10 x 8	15·134	12·611	10·810	..	..	..	..	..
10 x 10	18·917	15·764	13·512	..	..	..	..	..
12 x 8	21·792	18·160	15·566	13·620	..	..	..	..
12 x 9	24·517	20·430	17·512	15·323	..	..	..	..
12 x 10	27·241	22·701	19·458	17·025	..	..	..	..
12 x 12	32·689	27·241	23·349	20·430	..	..	..	..
14 x 12	..	37·078	31·781	27·808	24·718	..	..	..
14 x 14	..	43·258	37·078	32·443	28·838	..	..	..
18 x 14	..	..	61·292	53·631	47·672	42·904	39·004	33·754

TABLE XXXIX

Safe Distributed Loads in Tons for Jarrah Beams of Varying Spans.

Cross Section in Inches	Span in Feet							
	10	12	14	16	18	20	22	24
9 x 8	10·031	8·359	..	..	..	..	..	..
9 x 9	11·284	9·404	..	..	..	..	..	..
10 x 8	12·384	10·320	8·845	..	..	..	..	..
10 x 10	15·480	12·900	11·057	..	..	..	..	..
12 x 8	17·832	14·840	12·737	11·145	..	..	..	..
12 x 9	20·062	16·718	14·330	12·538	..	..	..	..
12 x 10	22·291	18·576	15·922	13·932	..	..	..	..
12 x 12	26·749	22·291	19·106	16·718	..	..	..	..
14 x 12	..	30·340	26·006	22·755	20·227	..	..	..
14 x 14	..	35·397	30·340	26·54	23·598	..	..	..
18 x 14	..	..	50·155	43·885	39·009	35·108	31·000	29·257

TABLE XL

Safe Distributed Loads in Tons for Oregon Beams of Varying Spans.

Cross Section in Inches	Span in Feet							
	10	12	14	16	18	20	22	24
9 x 8	6·347	5·289	..	..	..	..	..	..
9 x 9	7·140	5·950	..	..	..	..	..	..
10 x 8	7·836	6·530	5·597	..	..	..	..	..
10 x 10	9·795	8·162	6·996	..	..	..	..	..
12 x 8	11·283	9·403	8·059	7·052	..	..	..	..
12 x 9	12·694	10·578	9·067	7·933	..	..	..	..
12 x 10	14·104	11·754	10·074	8·815	..	..	..	..
12 x 12	16·925	14·104	12·089	10·578	..	..	..	..
14 x 12	..	19·198	16·455	14·398	12·798	..	..	..
14 x 14	..	22·397	19·198	16·798	14·931	..	..	..
18 x 14	..	..	31·735	27·768	24·683	22·215	20·195	18·512

TABLE XLI

Safe Distributed Loads in Tons for Ironbark Beams of Varying Spans.

Cross Section in Inches	Span in Feet							
	10	12	14	16	18	20	22	24
9 x 8	14·356	11·963	..	..	..	..	..	..
9 x 9	16·150	13·459	..	..	..	..	..	..
10 x 8	17·724	14·770	12·660	..	..	..	..	..
10 x 10	22·155	18·452	15·825	..	..	..	..	..
12 x 8	25·522	21·268	18·230	15·951	..	..	..	..
12 x 9	28·712	23·927	20·509	17·945	..	..	..	..
12 x 10	31·903	26·586	22·788	19·939	..	..	..	..
12 x 12	38·283	31·903	27·345	23·927	..	..	..	..
14 x 12	..	43·423	37·220	32·567	28·949	..	..	..
14 x 14	..	50·661	43·423	37·995	33·774	..	..	..
12 x 14	..	..	71·782	62·809	55·830	50·247	45·679	41·872

STEEL GIRDERS

619. Rivets. Before proceeding with the notes on design of steel beams it will be necessary to deal, if only but briefly, with the strength of rivets. The rivets are "stitches" used to connect the parts of a built-up girder together, and a great deal depends upon their being equal to the demands made upon their strength. Rivets fail by "shearing," or by "bearing," the latter being a bearing into or crushing either of the rivet into the plate or the plate into the rivet.

Fig. 134 shows failure by shearing. The right hand sketch illustrates single shear where the rivet has only to shear through one plane to give way. In the other sketch the rivet is shown in double shear where two planes have to be shorn

through. Obviously a rivet is twice as strong in double shear as in single shear. The strength of a rivet in single shear is but a matter of multiplying the cross sectional area in square

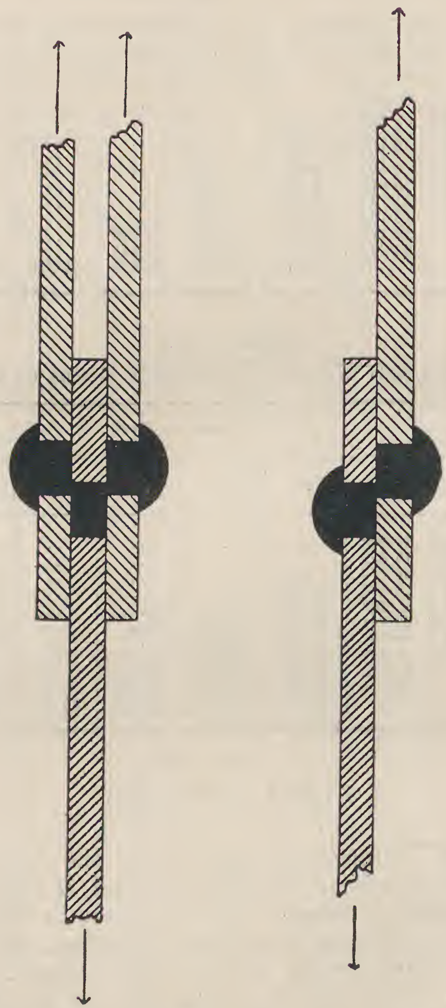


Fig. 134

inches by the strength of steel against shear per square inch. For example a $\frac{3}{4}$ in. diameter rivet has an area of ·4418 sq. in. Steel has a safe resistance of 13,500 lbs. per sq. in. Then ·4418 $\times$ 13,500 = 5,970 lbs. Fig. 135 shows failure due to bearing. The strength against bearing of a rivet is determined by

multiplying the thickness of the plate by the diameter of the rivet to find the bearing area and multiplying this area by the strength per square inch of steel against bearing.

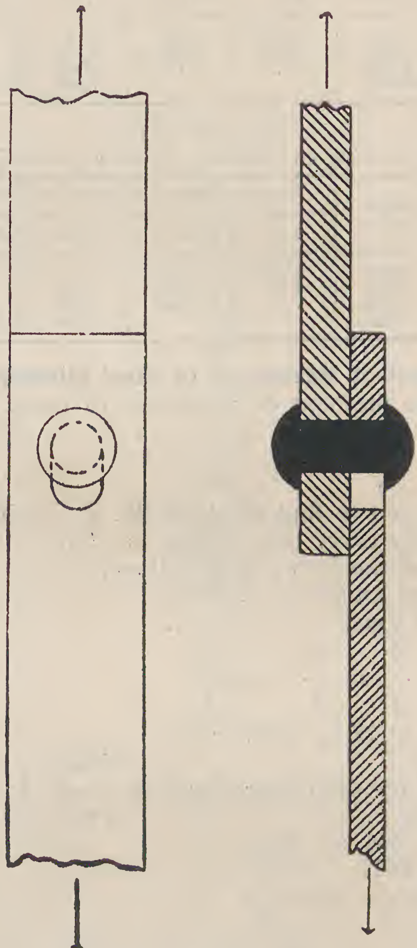


FIG. 135

For example, take a $\frac{3}{4}$ in. rivet in $\frac{5}{8}$ in. plate. Diameter of rivet × thickness of plate = ·75 in. × ·625 in. = ·46875.

Safe strength of steel against bearing = 22,500 lbs. per sq. in. Then ·46875 × 22,500 lbs. = 10,547 lbs. nearly.

Tables XLII and XLIII show safe shearing and bearing strength of steel rivets.

TABLE XLII

Safe Shearing and Bearing Strength of Shop Rivets in lbs.

Diameter of Rivet in parts of an inch	Single Shear	Bearing Strength in Plates of Different Thicknesses				
		$\frac{1}{4}$ in.	5/16 in.	$\frac{3}{8}$ in.	7/16 in.	$\frac{1}{2}$ in.
$\frac{5}{8}$	4,140	3,510	4,380	..	..	..
$\frac{3}{4}$	5,970	4,230	5,290	6,350	..	..
$\frac{7}{8}$	8,110	..	6,140	7,370	8,610	..
1	10,600	..	..	8,430	9,830	11,250

TABLE XLIII

Safe Shearing and Bearing Strength of Field Rivets.

Diameter of Rivet in parts of an inch	Single Shear	Bearing Strength in Plates of Different Thicknesses				
		$\frac{1}{4}$ in.	5/16 in.	$\frac{3}{8}$ in.	7/16 in.	$\frac{1}{2}$ in.
$\frac{5}{8}$	3,680	3,120	3,910	..	..	..
$\frac{3}{4}$	5,300	3,760	4,700	5,640	..	..
$\frac{7}{8}$	7,210	..	5,460	6,550	7,640	..
1	9,420	..	..	7,500	8,750	10,000

620. Moment of Resistance of Steel Girders. As described previously the moment of resistance of beam is M R which equals f z or $f \dfrac{I}{Y}$.

It is proposed to find the load the R S J indicated in Fig. 136a will safely carry over a span of 12 ft.

The data of the R S J is as follows:—

I about xx axis = 206·931.

f = 8 tons.

$$Y = \frac{d}{2} = \frac{12}{2} = 6 \text{ in.}$$

Span = 12 ft. or 144 in.

$$\text{Now B M for distributed load} = \frac{WL}{8}$$

$$\text{Therefore BM} = \text{MR}$$

$$\text{and } \frac{WL}{8} = f\frac{I}{Y}$$

$$W = \frac{8fI}{LY}$$

$$= \frac{8 \times 8 \times 206{\cdot}931}{144 \times 6}$$

$$= 15{\cdot}3 \text{ tons.}$$

This result includes the weight of the beam which must be

deducted to arrive at the superimposed load the beam will carry.

The above formula is used for all steel beams whether they be plated R S J's or plate web girders.

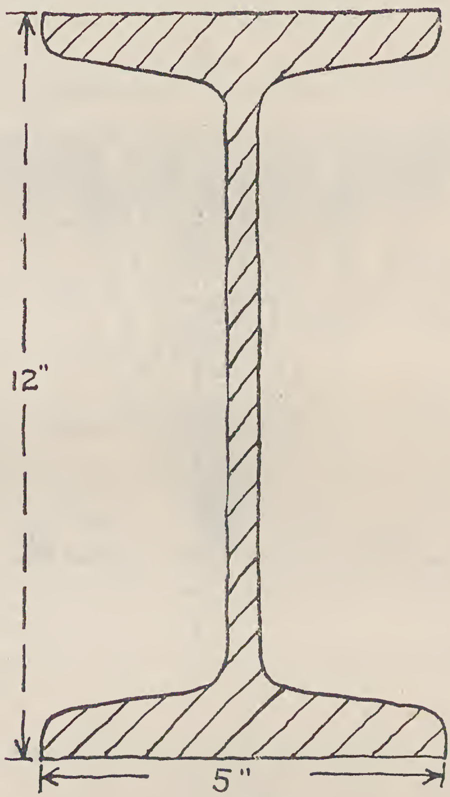


Fig. 136A

Suppose, for example, it was desired to select an R S J for a given load.

Take the previous example where the span is 12 ft. and the load is 15·3 tons and it is desired to select an R S J to suit the conditions.

Proceed as follows:—

$$BM = MR$$

$$\frac{WL}{8} = \frac{fI}{Y}$$

$$= fz.$$

Rewriting the equation

$$Z = \frac{W \times L}{8 \times 8}$$

$$= \frac{15{\cdot}3 \times 144}{8 \times 8}$$

$$= 34{\cdot}4$$

Consulting a steel handbook it will be found that an R S J

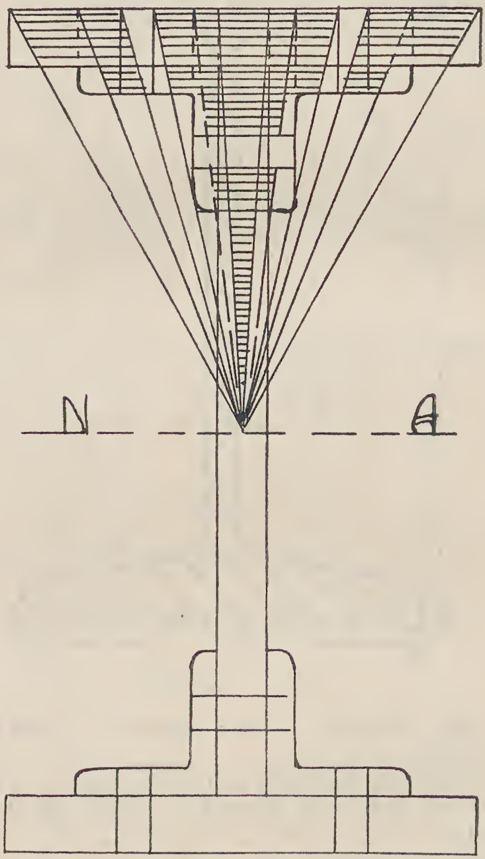


FIG. 136

having this figure as the section modulus is a 12 in. x 5 in. x 30 lbs. section.

Care must be taken in such calculations to allow for the weight of R S J.

621. Short Method of Calculation of Moment of Resistance of Steel Girders. Described in this article is a short method of arriving at the M R of an R S J on plate web girder. In this method the web section is not included in the calculation of the resistance to bending, the flanges alone being taken. The formula generally used is as follows:—

Let f = the safe tensile stress in tons per sq. in. of the material.

Let a = the area of the top or bottom flange.

Let d = distance between the centres of gravity of the top and bottom flanges.

Then M R = f a d.

Fig. 136 is a section of a plate web girder on which are projected the effective area of fibres. It will be seen that there is but a small error in taking the flanges of plate and L's as effective and neglecting the web.

The figure 137 shows a rolled steel section I beam. The parts shaded black of upper portion of beam is the area of flange taken.

The following give the data:—

a = area of flange — 8·067 sq. in.

f = safe strength of steel = 8 tons.

d = depth between centre of gravity flanges = 12·87 in.

L = span 20 feet = 240 in.

It is required to find the load W, that the beam will carry at its centre.

$$\text{Since } \frac{WL}{4} = f\,a\,d,\ W \times \frac{L}{4} = f\,a\,d$$

$$W = f\,a\,d \div \frac{L}{4}$$

$$= f\,a\,d \times \frac{4}{L} = \frac{4\,f\,a\,d}{L}$$

$$\text{Then } W = \frac{4 \times 8 \times 8{\cdot}06 \text{ sq. in.} \times 12{\cdot}87 \text{ in.}}{240 \text{ in.}} = 13{\cdot}8 \text{ tons.}$$

If we require a greater strength than is afforded by this steel beam we may place plates on the top and bottom, which are to be secured to it with rivets. See Fig. 138. Having

determined the carrying capacity of the beam reinforced with these plates it will be necessary to provide that the rivets shall be sufficient to resist the horizontal shear which will tend to separate the plate from the flange of the girder.

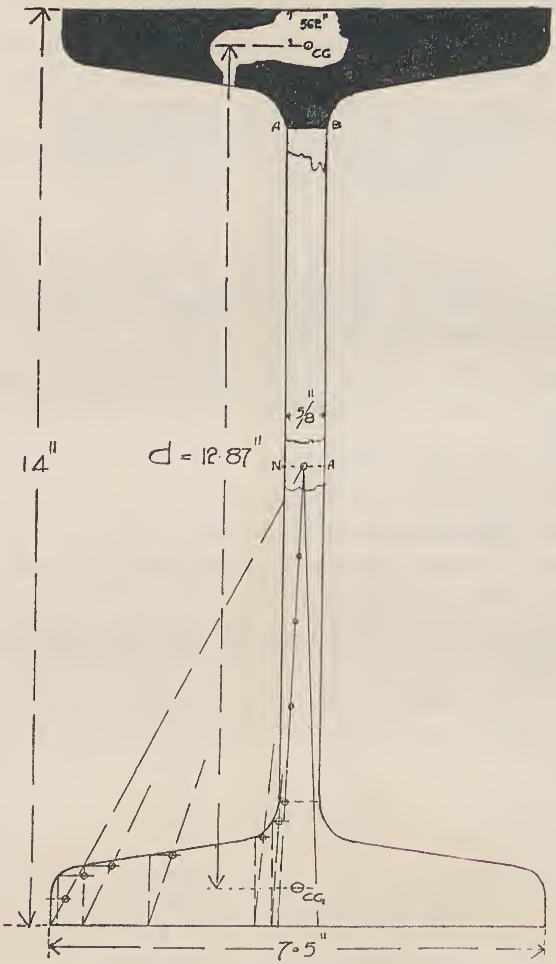


Fig. 137

The procedure will be as follows:—

Let it be supposed that a 9 in. x 1 in. plate is to be added to each flange.

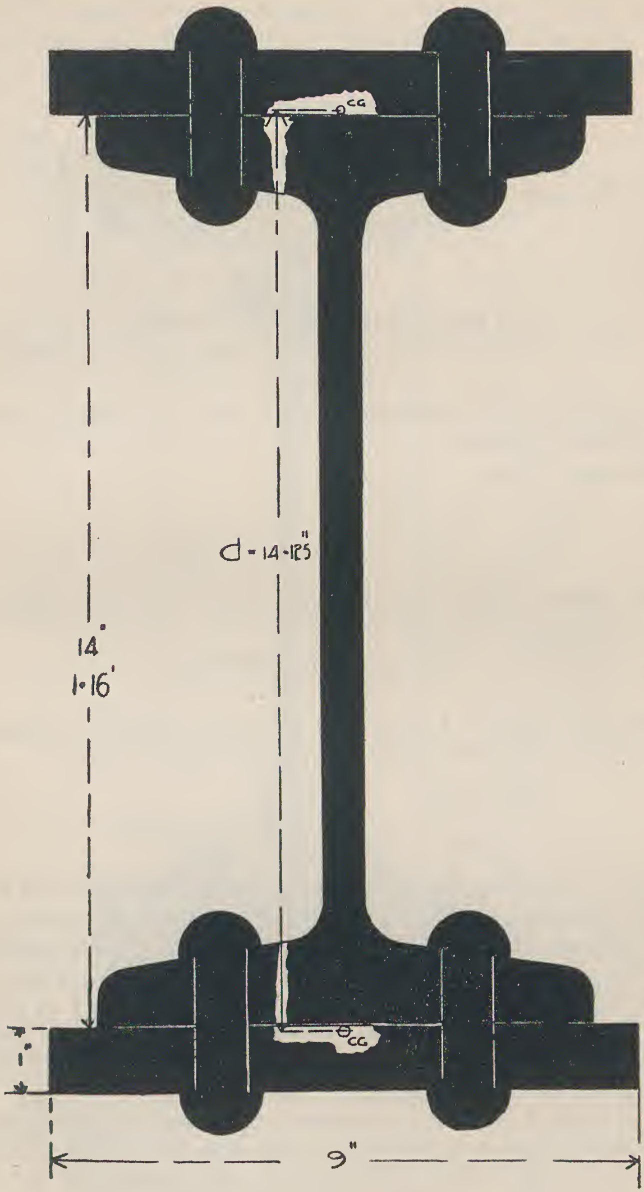


FIG. 138

$$\begin{aligned}
\text{Area of flange} &= 8{\cdot}067 \text{ sq. in.}\\
\text{Area of plate} &= 9{\cdot}0\\
\hline
\text{Total area} &= 17{\cdot}067\\
\text{Less holes for } \tfrac{3}{4} \text{ in. rivets} &= 2{\cdot}075\\
\hline
\text{Total effective area} &= 14{\cdot}992 \text{ sq. in.}\\
\text{The distance between centres of gravity} &= 14{\cdot}125 \text{ in.}\\
\text{The formula is } W &= \frac{4\,f\,a\,d}{L}
\end{aligned}$$

$$\text{Then } W = \frac{4 \times 8 \text{ tons} \times 14{\cdot}99 \text{ sq. in.} \times 14{\cdot}125 \text{ in.}}{240 \text{ in.}} = 28{\cdot}23 \text{ tons.}$$

It must now be ascertained that rivets are strong enough and properly spaced.

The total shear will be—

$$\frac{W}{2} = \frac{28 \text{ tons}}{2} = 14 \text{ tons.}$$

The depth between plates is 1·16 ft. Then the shear per

$$\text{foot} = \frac{14 \text{ tons}}{1{\cdot}16} = 12{\cdot}07 \text{ tons, or } 27{,}036 \text{ lbs.}$$

From the table XLII it will be found that $\frac{3}{4}$ in. diameter rivets will each stand 5,970 lbs. single shear. Then

$$\frac{27{,}036 \text{ lbs.}}{5{,}970} = 4{\cdot}6 \text{ rivets per foot.}$$

Say, 6 rivets per foot, that is, 3 on each side at 4 in. pitch.

This method of using a steel beam reinforced with plates is an economical one and can be recommended, for it dispenses with the necessity for the labour entailed in making the connection of web to the flanges, as would be necessary in a plate web girder. The economy in construction more than counterbalances the slight waste of material which takes place in the flanges of the beam.

Fig. 139 is a section of a plate web rivetted girder, having a span of 21 ft. 1 in. or 253 in. In this case the web is designed to resist the vertical shearing stress, and must also be made sufficiently thick to resist buckling, due to the diagonal stresses previously mentioned. The flanges are designed to

resist the bending moments, and the web and flanges are connected together by means of L's and rivets. The rivets must be strong enough to resist shearing, and also must be

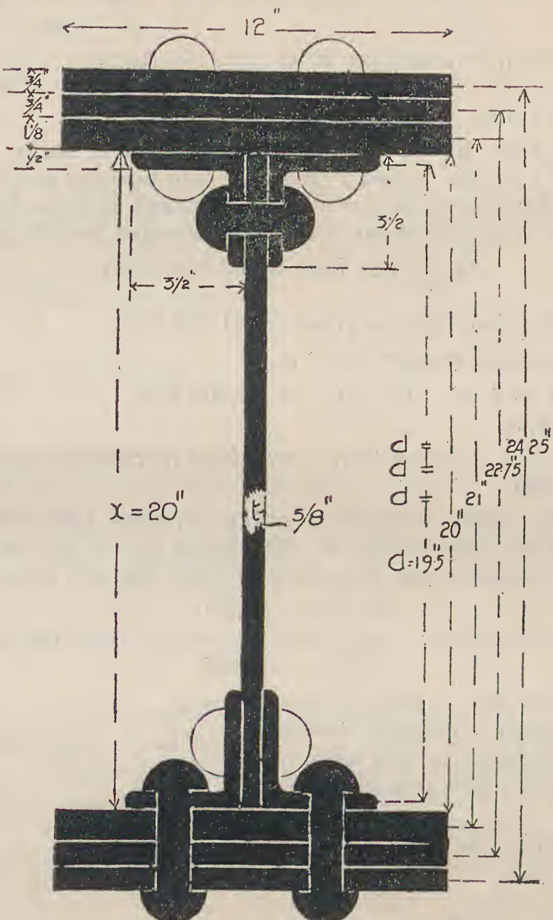


FIG. 139

sufficiently large to prevent crushing of the rivet and tearing of the plate by the rivet. The working out of the example will be as follows:—

Approx. weight of girder	=	2·75 tons
Load at centre of girder	=	77 tons
Total load	=	79·75 tons

$$\text{Max. B M} = \frac{WL}{4} = \frac{79{\cdot}75 \text{ tons} \times 253 \text{ in.}}{4} = 5{,}044 \text{ inch tons.}$$

Shear per foot horizontal and vertical when depth of girder taken as depth of web = 20 in. or 1·66 ft. $= \frac{39{\cdot}875 \times 2{,}240}{1{\cdot}66 \text{ ft.}}$ = 53,807·2 lbs.

Rivets 1 in. dia. stand 10,600 lbs. safe single shear.
Rivets 1 in. dia. stand 10,908 lbs. safe bearing in ⅝ in. plate.
Then No. required per foot to connect web to L's where rivets are in double shear will be determined as follows:—

$$\frac{\text{Shear per foot} = 53{,}807{\cdot}2 \text{ lbs.}}{\text{Double shear for one rivet} = 21{,}200 \text{ lbs.}} = 2{\cdot}5 \text{ rivets.}$$

Safe bearing strength of 1 in.
rivet in ⅝ in. web plate = 10,908 lbs.

then $\frac{53{,}807{\cdot}2}{10{,}908}$ = practically 5 per foot to resist bearing.

Web to resist vertical shearing stresses and buckling:—
Depth of web = 20 in. Thickness = ⅝ in., or ·625 in.
Shear in web must not exceed 10,000 lbs. per sq. in.

$$\text{In this case shear} = \frac{39{\cdot}875 \times 2{,}240}{20 \text{ in.} \times {\cdot}625} = 7{,}145 \text{ lbs. per sq. in.}$$

Formula for buckling stress where—
d = straight portion of web.
t = thickness of the web.
s = safe stress per sq. inch.

$$s = 5{\cdot}5 - {\cdot}04 \frac{d}{t}$$

$$= 5{\cdot}5 - {\cdot}04 \times \frac{13}{{\cdot}625}$$

= 4·66 tons per sq. inch.
Area of web = 20 × ·625 = 12·5 sq. ins.

∴ 12.5 × 4·66 = 58·25 tons = safe shearing stress web will bear. This is satisfactory because maximum shear $= \frac{79{\cdot}75 \text{ tons}}{2}$ = 39·875 tons.

M R^s of L^s and plates.

M R = f a d, where f = 8 tons, a = area, d = depth between centres of gravity.

Areas:—

$L^s = \frac{1}{2}$ ($3\frac{1}{2}$ in. + $3\frac{1}{2}$ in.)	=	3·5 sq. in.
less rivet holes	=	1·0
		2·5

Plates:—

12 in. x $1\frac{1}{8}$ in.	=	13·5 sq. in.
less rivet holes	=	2·25
		11·25
12 in. x $\frac{3}{4}$ in.	=	9·0 sq. in.
less rivet holes	=	1·5
		7·5

M R L^s = 8 x 2·5 × 19·5	=	390
M R 12 in. x $1\frac{1}{8}$ in. plate = 8 x 11·25 x 21	=	1,890
M R 12 in. x $\frac{3}{4}$ in. plate = 8 x 7·5 x 22·75	=	1,365
M R 12 in. x $\frac{3}{4}$ plate = 8 x 7·5 x 24·25	=	1,455
Total of moments of resistance		5,100

The use of the diagram of Bending Moments is illustrated in this example. (See Fig. 140.) It would be a great waste of material to allow the flange plates to go the whole length of the girder, since the bending moments decrease rapidly towards and become nothing at the points of support. Of course, for practical reasons the L^s and the nearer plate to them at top and bottom must be continued to end of girder. But the others should be stopped off as soon as possible. By setting up to the same scale as that used for the Max. B M, the value of M R of each plate, and drawing horizontal lines it will be seen where the plates pass beyond the diagram of B M's. The unnecessary portions may be cut off by vertical lines as shown, and the actual lengths of plates required may be measured off to the same scale as the span of girder.

622. Construction of Steel Girders. Girders as members in building construction must be stiff enough to have but a very

small deflection. If girders have a deflection of more than $\frac{1}{360}$ part of the span cracked plaster of walls and ceilings will most likely result. A deflection greater than this can usually

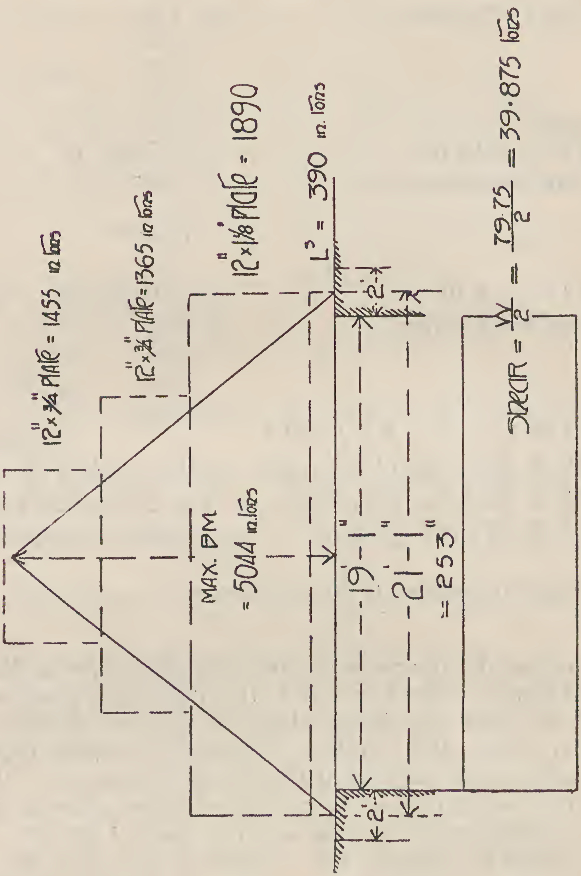


FIG. 140

be guarded against by having the depth of the beam not less than $\frac{1}{20}$ of the span. It is also wise to design the girders as deep as possible, for the deeper the girder, the greater the leverages involved in the moments of resistance, and consequently the smaller will be the areas of flanges required.

Further than this, the shearing stress per foot will be less, and consequently the size of rivets diminished and spacing apart of rivets increased. Lateral stiffness in the case of girders unsupported at the sides is also a matter that must not be overlooked. The unsupported length of girder should not exceed 20 times the width of the flanges. When using a very wide flange in the case of a girder having a single web, there may be a danger of having the flange projecting sideways beyond the L^s too much. This projection should not be more than eight times the thickness of the flange.

In the construction of the girder it is an essential point that the holes be drilled and not punched.

In a test recently made the advantage of drilled holes was well illustrated. In one case the holes were punched, and in the other case drilled. The plates were subjected to the cold-bending test. It was seen that the plate in which the holes were punched had perceptibly failed, while the other stood the test perfectly. The plates and L^s should be drilled together, otherwise "rymering," and "drifting" would be required, in which case the rivets would probably be a bad fit.

CHAPTER XI

ROOF DESIGN

623. Fig. 141 represents by direction, three forces meeting at a point. To maintain a condition of equilibrium, they must be in the one plane, and be represented in magnitude and direction by the three sides of a triangle. For the purpose of identifying each force with its corresponding side of the triangle, it will be necessary to name them. The best method is to place letters between the forces and to call each force by the two letters between which it appears. For example, the

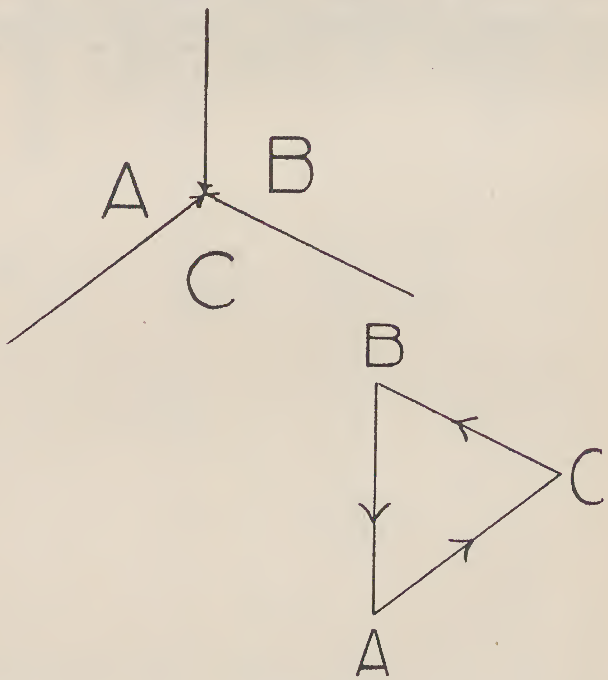


FIG. 141

upper force would be named AB, since these letters are placed one on each side of it. The other two forces are BC and CA respectively. The triangle ABC, known as the "triangle of

forces," represents in direction and magnitude the three forces AB, BC and CA. It will be noticed that the letters identifying the lines necessarily appear at the ends of the lines in the triangle. This is an excellent arrangement of notation, since its adoption prevents confusion when the principle of the triangle of forces is applied to complicated braced frames such as roof trusses. The arrows on the forces in sketch (Fig. 141), shows the directions of the forces.

The arrows on the sides of the triangle must correspond, and must also be continuous in direction. That is to say they must all go the one way round.

624. The use of the triangle of forces may be illustrated by the following: The two forces AB and BC may be known in magnitude and direction. It is required to determine the direction and magnitude of a third force to provide for equilibrium. Draw two lines parallel in direction and to scale for magnitude, as two sides of a triangle. The third side of the triangle will indicate the direction, and its length by the same scale as used for the others, will give the magnitude. Again, the magnitude of one force and the direction of the three may be known, in which case the drawing of the triangle will give the magnitude of the others.

625. The principle briefly described above may be applied as a further example to the case of a triangular timber frame as a simple roof truss. Fig. 142 illustrates such a frame. It rests on two piers, the reactions through which are indicated by lines and named AD and BD respectively. The weight or force on the frame is AB. The rafters and the beam of the frame are respectively AC, BC, and DC. It is required to determine the magnitude and character—tension or compression—of the stresses in the rafters and tie beam due to the load AB, and its reactions AD and BD.

Draw a line AB parallel to the force AB, and its reactions AD and BD. Make this line to a length of some scale to represent the magnitude of the weight or force AB. Suppose AB to be 10 tons and the scale 1 ton to $\frac{1}{4}$ in. Then AB would be $2\frac{1}{2}$ in. long. From the ends of AB draw lines parallel to the rafters AC and BC. Mark the point of meeting of these lines as C. From C draw a line parallel to DC. Name the point where the line cuts AB as D. An inspection of the frame diagram will show that there are three groups of forces acting on it, namely: (1) The load and the two rafters at the top; (2) At the left hand end: the reaction AD, a rafter, and tie beam; (3) At the right hand end: the reaction BD, a rafter, and tie beam.

Take the top group first. They are AB, BC, and CA. The corresponding lines on the stress diagram will give the stresses in the two rafters BC and CA. The left hand group may next be taken. This group is DA, AC, and CD. DA is the reaction and in this case will be equal to half AB, as shown on the load diagram. The lines AC and CD on the stress diagram measured off to scale will give the stresses in the rafter and the beam respectively. Of course the rafter has already been considered in the top group, and has only been

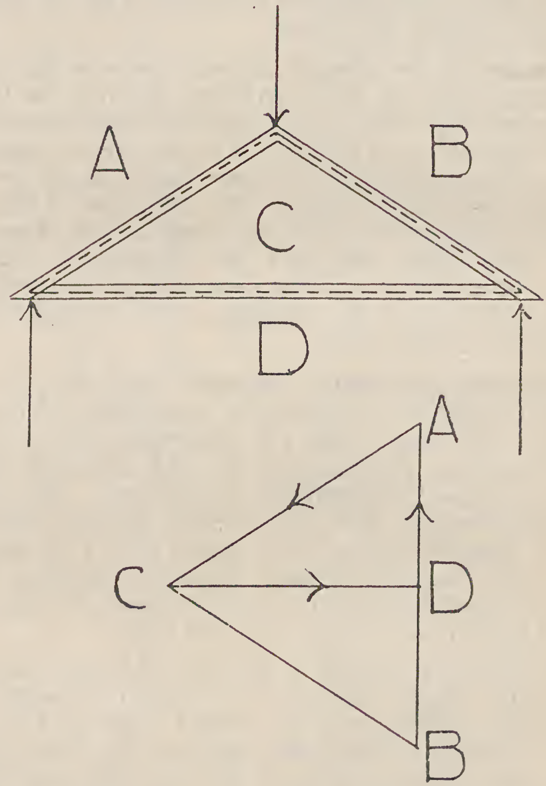


FIG. 142

taken again to allow of considering the group at the end. It will be obvious that a member in more than one group must in each group have the same stress. The process for finding the stresses in the groups on the right hand will be the same as for the left hand group. One of the groups in this frame may be selected as an illustration of the method of determining

the character of the stress in any member of a frame. Take the left hand group. The direction of one of the forces DA is certainly known. This is the reaction, and acts upwards. Mark

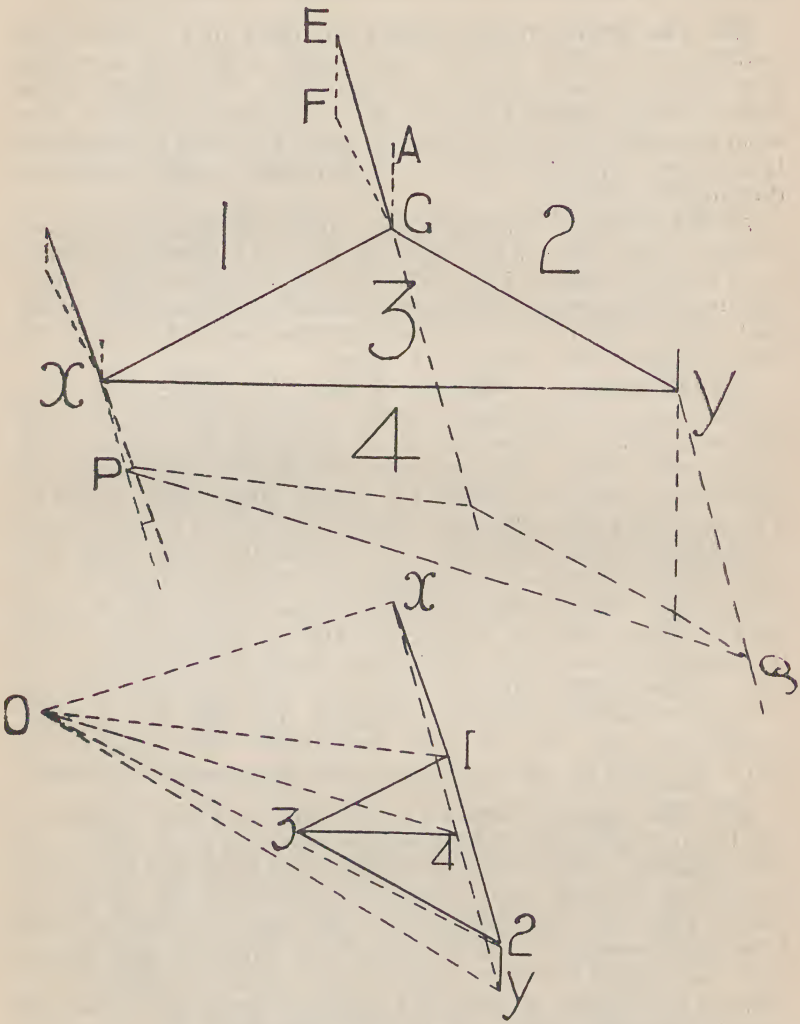


Fig. 143

an arrow, indicating the direction on the stress diagram. Then since the arrows must all go the one way, the directions of the stresses AC and CD may be found by marking the arrows

in conformity with this rule. It will be seen that the stress in AC is towards the point at which the members of the group act in the frame design; hence it is a compression stress. The stress CD is away from the point, and is a tension stress.

626. The forces on the single roof frame in Fig. 143 is an example of the way in which the weight of the roof covering is applied at various points of a roof truss. The weight of the roof covering is always taken to act vertically downwards. The wind pressure, however, cannot be taken as acting downwards. It must be considered to act in a direction at right angles to the slope of the roof.

At the points of application of a roof covering to a braced frame or truss there will, therefore, be two forces to consider. (1) The dead weight of the roof covering acting vertically; and (2) the wind pressure acting perpendicular to the slope of the roof. These two forces may, however, be resolved into one on the principle of the triangle of forces.

Fig. 143 shows an example of this. AG is the proportion of the roof covering dead weight acting at the top point of the frame. FG is the amount of the wind pressure transmitted by the roof surface to this point. These two forces may be resolved into one by making EF = AG, and joining E and G. The line EG is the resultant of the two forces FG and AG, both in magnitude and direction. The resultant of the wind and dead load at the lower left hand end has been found in the same way. On the right hand side the loads will be dead weight only, since the wind will only act at one side. It is, perhaps, just as well to state here that in determining the stresses, the wind is taken on one side. The maximum stresses in the bars on this side due to wind on this side, and the dead weights on both sides, are then determined. Both sides of the frame are then designed alike to resist the maximum stresses.

627. The external forces due to wind and dead loads on the frame in Fig. 143 will therefore be x - 1, 1 - 2, and 2 - y. The amounts of these forces will be known so that they may be set out to scale, as has been done in the lower portion of sketch Fig. 143. By joining x to v the total reaction of these external forces will be obtained, both by direction and magnitude. To divide x y into proportionate parts to represent the amount of reaction at each end of the frame, it will be necessary to draw the polar and funicular diagram.

628. The polar diagram is found as follows: Mark any point O and join it by straight lines to the points x, 1, 2 and y. These lines, in conjunction with the lines x - 1, 1 - 2, and 2 - y form the polar diagram.

629. To draw the funicular diagram proceed as follows: Draw lines parallel to x y from each end of the frame diagram. These lines will be directions of the reactions. Commencing from a point anywhere on the left hand line of reaction draw a line parallel to o x until it cuts the line of force x - 1. From where line x - 1 was cut draw a line parallel to o - 1 until line of force 1 - 2 is cut. From this draw a line parallel to 0 - 2 to meet or cut 2 - y, from which intersection a line is to be drawn parallel to o - y to meet the line of reaction at the right hand end. Join the points on each line of reaction. This line pq will close the funicular polygon. Draw from O a line parallel to pq. This line cuts xy at 4. The point 4 divides xy into the two parts to represent respectively the reactions at the ends of the frame. X4 is the left hand, and 4y the right hand reaction.

630. Having the external loads and reactions, it will be possible to draw the stress diagram.

631. The group at the left hand corner is x - 1, 1 - 3, 3 - 4 and 4 - x. From the point I draw a line parallel to bar 1 - 3 of frame. From the point 4 draw a line parallel to bar 3 - 4 of frame. These two lines will meet at 3. By commencing with line x - 1 in the stress diagram, and following on with lines 1 - 3, 3 - 4, and 4 - x, the stresses in the bars of the group may be determined. Likewise may be determined the top group 1 - 2, 2 - 3, and 3 - 1. Also the right hand end group 2 - y, y - 4, 4 - 3, and 3 - 2. It will be observed that in the stress diagram each group is represented by a series of lines which follow one another, the last of which ends at the point of commencement of the first. This orderly running and final closing is a feature that must be observed for each group of forces in every stress diagram.

632. Fig. 144 shows a roof truss with the wind acting on the left hand side. The wind and dead loads have been resolved into single forces at each point of bracing along the principal rafter on the principle as described in the last article. The various external loads x - 1, 1 - 2, 2 - 3, 3 - 4, 4 - 5, 5 - 6, and 6 - y are set out in the lower diagram. The resultant x, y, of these loads is divided at the point 15 by the line 0 - 15 of the polar diagram, and gives the reactions x - 15 and 15 - y.

633. The funicular polygon in this figure has its sides named to agree with the corresponding lines in the polar diagram. This may help to remove any difficulties in the mind of the student after having read the descriptions in the previous article.

634. The stress diagram is indicated by dark lines, and

though at first it may appear somewhat complicated, a little study of it will soon clear away any difficulties, for it will be found that it is but an extension of the more simple case

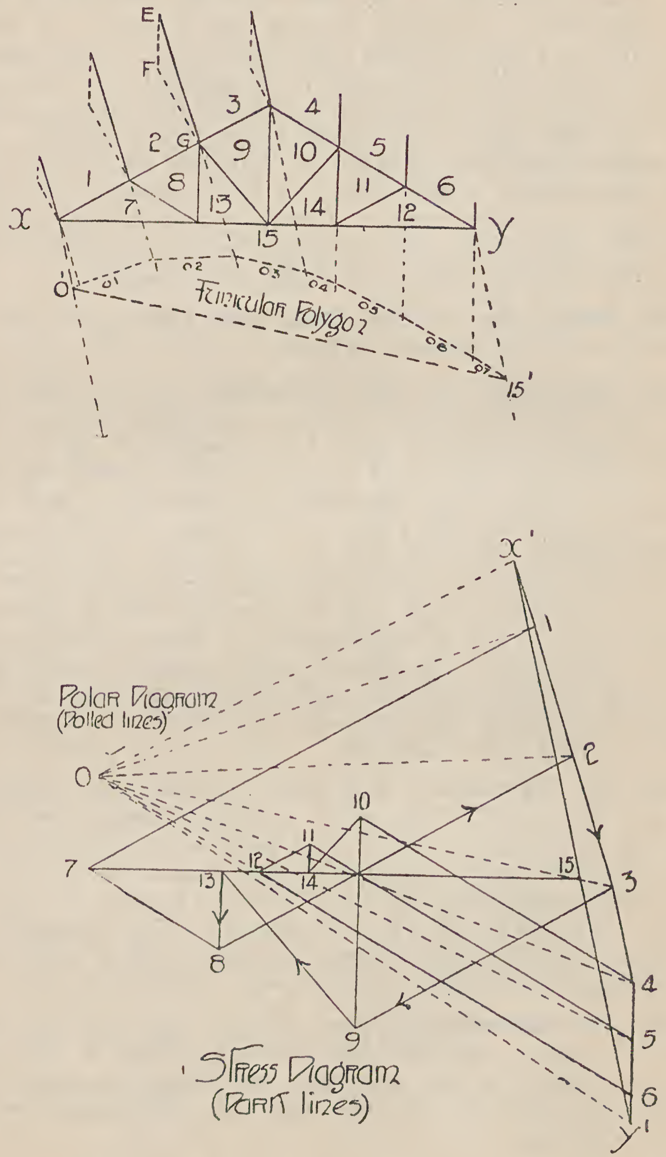


FIG. 144

described in Art 631, *ante.* One or two groups of forces in the frame may be taken to illustrate the working of the stress diagram. Take the group at the left hand end of the frame. The forces in this group are x - 1, 1 - 7, 7 - 15, and 15 - x. The corresponding stress lines for these may very easily be followed in the stress diagram. Commencing at x′, we can follow lines having the number x′ - 1, 1 - 7, 7 - 15, and 15 - x′ at their extremities. These lines will represent the magnitude measured to the scale of the diagram, and the various directions of the forces acting at the left hand end of the frame. Two of these are in members of the frame, and consequently are the stresses acting in these members. An interesting group acts at the second point up the principal rafter of the frame. This group is: 2 - 3, 3 - 9, 9 - 13, 13 - 8, and 8 - 2. Commencing at the point 2 we can follow the lines having the numbers 2 - 3, 3 - 9, 9 - 13, 13 - 8, and 8 - 2 at their extremities. Only one of these, 2 - 3, is an external load, and all the others are stresses in bars in the frame. The arrows running "one way round" in this group are shown in the stress lines to indicate the character of stress exerted. It will be seen that only one acts away from the point in the frame; all the others towards the point, and are consequently in compression. All the other groups may be named and followed in the stress diagram in the same way. The arrows running one way may be put in each group, as described above. It should, of course be remembered that the first arrow will be put in in accordance with the direction of one of the known forces—usually one of the external forces.

635. Distribution of Weight of Roof Covering over Principals. The Fig. 145 shows section of a roof. The principal is indicated by dotted lines. Each purlin carries half the load of rafters, roof covering, and wind pressure between it and the next one. This being the case, it will follow that the purlin at E will have to carry the amount of wind pressure, roof covering for rafters between A and B. Likewise, the purlin at F will carry the load from B to C. The purlins discharge their loads at the points where they bear on the principal. Therefore, the point E of the principal will have to bear the wind pressure, weight of roof coverings and rafters, and purlin from A to B, and from midway between it and the principal on each side. Assume, for the sake of example, that the distance from A to B is 10 feet, and that the principals are 12 feet apart, then the point E of the principal would have 120 sq. feet of wind pressure roof covering and rafter weight placed on it. The weight at the other points would be determined on the same principle.

636. The Weight per sq. foot of Roof Covering and Rafters will, of course, depend on the kinds of material and timber used. In the chapter on roof coverings will be found a table of weights per sq. foot of the different kinds of material.

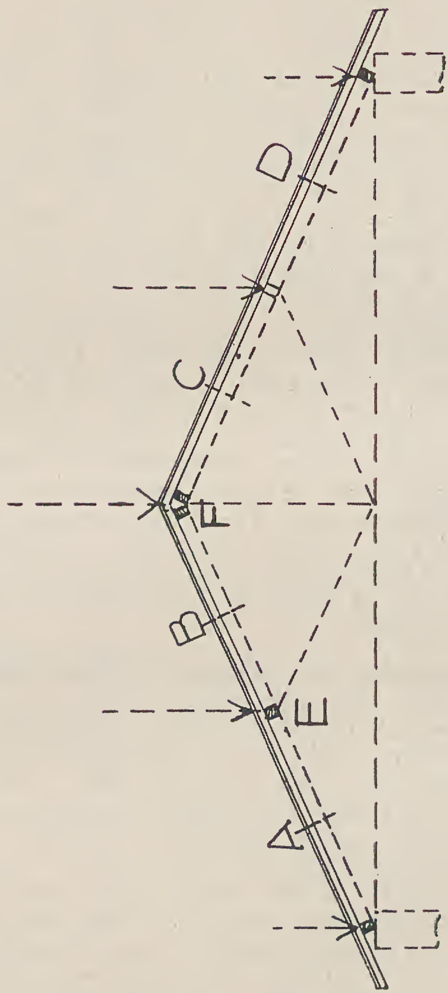


Fig. 145

637. The Wind Pressure must be taken at maximum, and its effect on the roof will depend on the slope of the latter. The greater the angle the greater the effect of the wind. It is assumed that the maximum horizontal force of the wind is 50 lbs. per sq. foot. This pressure must be resolved into a

normal or perpendicular pressure for each slope of roof. The Table XLIV gives normal wind pressure for various roof pitches.

TABLE XLIV

Normal Wind Pressure on Roofs. Force of wind = 50 lbs. per sq. foot

Angle of inclination of roof	10°	20°	25°	26° 34′	30°	40°	50°	60°
Normal pressure in lbs. per sq. foot ..	12	22·5	28·8	29·5	33	41·5	47·5	50

638. Design of a Truss for a Roof of 50 feet Span. The foregoing description of the principles underlying the method

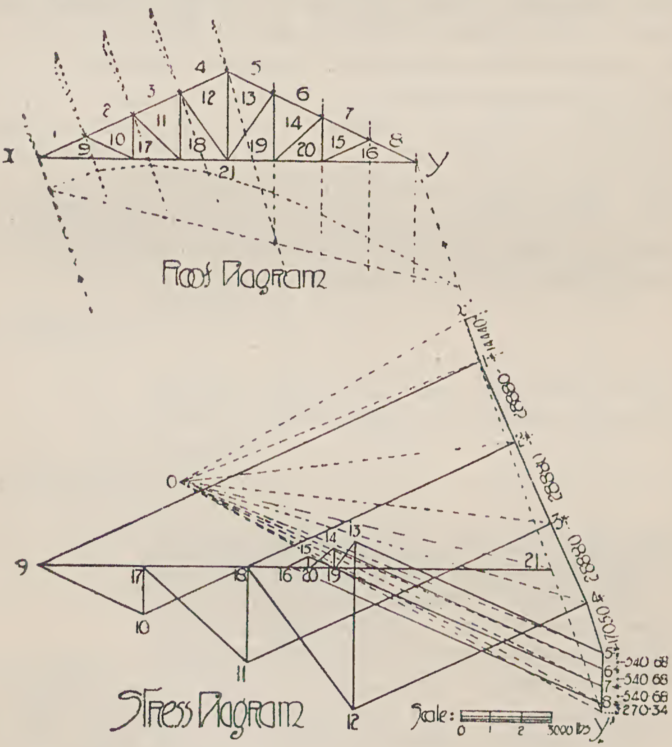


FIG. 146

of determining the stresses in roof trusses has necessarily been of the very briefest nature. The student is, therefore, advised to practise the principles in application to different forms of

roof trusses or frames. When some practice has been made, the following directions for the design of a roof truss may be studied: Fig. 146 shows the frame or roof diagram for a roof with a span of 50 feet, and in which the trusses are spaced 12 feet from centre to centre. The galvanized iron is supposed to be secured to purlins, so that there would be no rafters.

24 gauge galvanised iron	1·6 lbs. per sq. foot
Screws and Washers	·2 ,, ,, ,, ,,
6 in. x 4 in. Oregon pine purlins	1·73 ,, ,, ,, ,,
Weight of principal	3·00 ,, ,, ,, ,,
Total	6·53 ,, ,, ,, ,,

Wind Pressure. Pitch of roof = 25 deg. Normal wind pressure for this pitch = 28·8 lbs. per sq. foot.

The area of roof resting on each side of truss is:—

Length of Principal Rafter	=	27·6 ft.
Width of Roof resting on Truss	=	12·0 ft.
Then the area = 27·6 x 12	=	331·2 sq. ft.
The total dead weight on each side of truss will be — 6·53 x 331·2	=	2,162·73 lb.

A quarter of the total dead load will be carried at each of the intermediate points of bracing.

$$= \frac{2162 \cdot 73}{4} = 540 \cdot 68 \text{ lbs.}$$

The end of the truss will carry only half the amount carried by the intermediate points.

$$= \frac{2162 \cdot 73}{8} = 270 \cdot 34 \text{ lbs.}$$

The top point will also carry half the amount of the intermediate points on one side, but it also carries a similar amount from the other side of roof, consequently the top will have the same as the intermediate points, namely .. .. 540·68 lbs.

These amounts of dead load are to be set out to scale on vertical lines at the respective points, on both sides of truss.

The total wind pressure on one side of truss will be:—

$$331 \cdot 2 \times 28 \cdot 8 = 9538 \cdot 56 \text{ lbs.}$$

A quarter of this will be carried at the intermediate points and $\frac{1}{8}$ at the top and bottom points of truss.

$$\text{Amounts on top and bottom points} = \frac{9538{\cdot}56}{4} = 2384{\cdot}64 \text{ lbs.}$$

$$\text{Amounts on top and bottom points} = \frac{9538{\cdot}56}{8} = 1192{\cdot}32 \text{ lbs.}$$

These amounts are to be set out to scale on lines perpendicular to the roof slope at the respective points on *one side of roof truss only*. In the drawing Fig. 146, they are shown on the left hand side of truss.

The dead and wind loads on the left hand side are to be resolved into single equivalent loads at each point. This is shown as having been done on the drawing. Lines parallel, each to scale, representing the various resultants of wind and dead loads for left hand side, and the dead loads for the right hand side, are then to be drawn, each following on in proper order at a convenient distance below the roof diagram. The direction of reactions, and the polar and funicular diagrams are next to be drawn very carefully. The stress diagram is then to be completed, and properly named at its different points. The greatest care and neatness in drawing everything in connection with the stress diagram will be absolutely necessary, otherwise the final lines of the diagram will not meet, or what is technically called "close." Should difficulty of this kind arise, either the drawing has been faulty, or a mistake has been made. In any case, the diagram will be useless unless it closes properly.

In the event of success with the stress diagram, the stresses on the various members of the truss may be scaled off from the stress diagram, and systematically tabulated. The Table XLV gives such a systematic tabulation of the stresses in the truss now being dealt with. It will be seen that each member on one side of the truss has a column allotted to it. The column contains the stress expressed in lbs., and the length in inches. The members are also grouped under compression or under tension, as the character of the stress may be.

TABLE XLV

Giving Lengths and Stresses in Members of Roof shown in Fig. 146.

Character of Stress	Compression								Tension			
Names of members .	1–9	2–10	3–11	4–12	5–13	9–10	17–11	18–12	21–9	10–17	11–18	12–13
Stress in lbs.	16,000	13,500	11,000	8,500	9,000	3,850	4,700	5,900	17,000	1,600	3,200	5,600
Length in ins.	82·5	82·5	82·5	82·5	82·5	82·5	102	126	..	..	..	..

639. It now remains to properly proportion the various members of the truss to safely resist the stresses.

640. With a view to variety of example two kinds of truss will be calculated, namely:—

(1) A timber truss with steel tension rods.

(2) A steel truss.

It would have been a better design to have had the tie rod cambered to a noticeable extent for the steel truss, but the limits of this little book make it impossible to give the extra space for a diagram for each. The principle of the method is, however, precisely the same, and in practice the student will find no difficulty in making a diagram for a truss of this kind with the rod cambered.

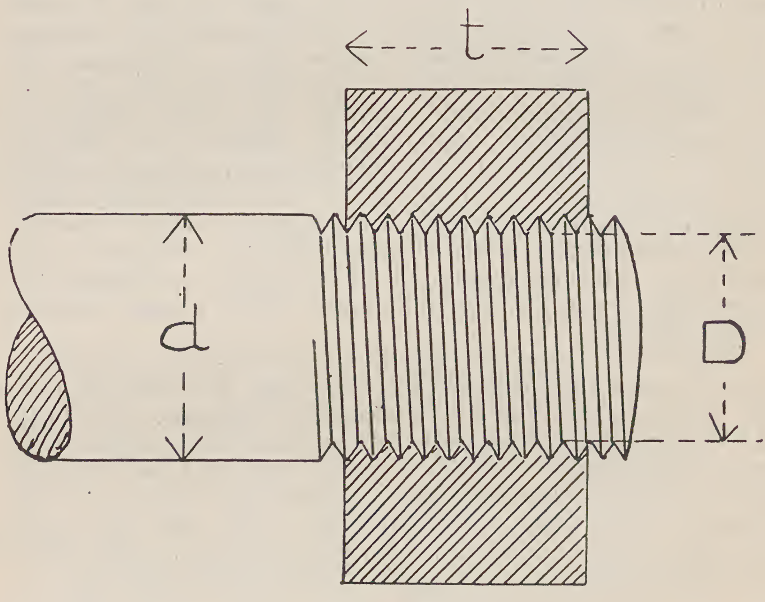


FIG. 147

641. Sizes of Sections of Timber and Steel Truss for 50 feet Span. The tie-beam principal rafters and struts to be of oregon pine, vertical tension rods to be of steel. Proceeding in the proper order the sections of the steel rods must first be determined. The ends of these rods are screwed. It will therefore be necessary to allow for diminution of area due to screw cutting, and also to provide for sufficient thickness of nut to prevent failure by shearing of threads. Fig. 147 shows screwed end of a rod. This has a minus thread, that is one cut into the

rod. It will be evident that the area of the rod is reduced from a circle having d as a diameter to a circle having D as diameter. The area of the rod available to resist tension is that with D diameter. In designing the rod, a circle of the area required to resist tension is determined. The diameter of this circle is taken to be D. The extra diameter required for thread is then computed. This diameter (d) is taken as diameter of rod. Having D the value of d may be computed by the formula:—

$$d = \frac{D + \cdot 06}{\cdot 9}$$

It may seem wasteful to make the whole rod of extra diameter, because there has been a reduction at one end. To avoid this extra amount of diameter, it would be necessary to thicken or "upset" the end of the rod, so that the thread would be what is called "plus." As a rule, however, it costs more to do this than to allow of greater diameter throughout, as in the case of the "minus" thread.

642. The rod may fail under its load by the threads being "stripped off," thus allowing the nut to get free. By cutting a thread in proportion to the diameter of the rod, and by making the thickness (t) of the nut equal to (d), a sufficient margin of safety will be provided.

643. The areas of the rods may now be determined. In the calculations we may allow a safe stress of 18,000 lbs. per sq. inch for steel.

Rod 10 — 17. Stress 1,600 lbs.

$$\text{Area of rod} = \frac{\text{stress}}{18{,}000 \text{ lbs.}} = \frac{1{,}600}{18{,}000} = \cdot 088 \text{ sq. inches.}$$

A circle having an area of ·088 of a sq. inch will have a diameter of ·343 inch approx. Consequently, the diameter D = ·36 inch. By the formula—

$$d = \frac{D + \cdot 06}{\cdot 9} = \frac{\cdot 343 \text{ in.} + \cdot 06}{\cdot 9} = \cdot 44 \text{ ins.}$$

This would practically be a rod ½ in. in diameter.

644. The tie beam next requires consideration. It is to be of oregon pine. The safe tensile stress for this timber may be taken as 570 lbs. per sq. inch. It will be found that a 9 in. x 4 in. section will meet the requirements. The greatest stress is in the end sections. Let the end named 21 - 9 in the table be taken. The stress in this portion is 17,000 lbs.

The area required will be—

$$= \frac{\text{stress}}{570 \text{ lbs.}} = \frac{17{,}000}{570} = 29{\cdot}8 \text{ sq. inches.}$$

This area must be left at any cross section after all cuts and holes are made. The worst section would be vertically through the under edge or toe of principal rafter. Sketch A, Fig. 148, shows that the cut right across to provide a toe bearing for the principal rafter goes 1 inch down. The section at this place is

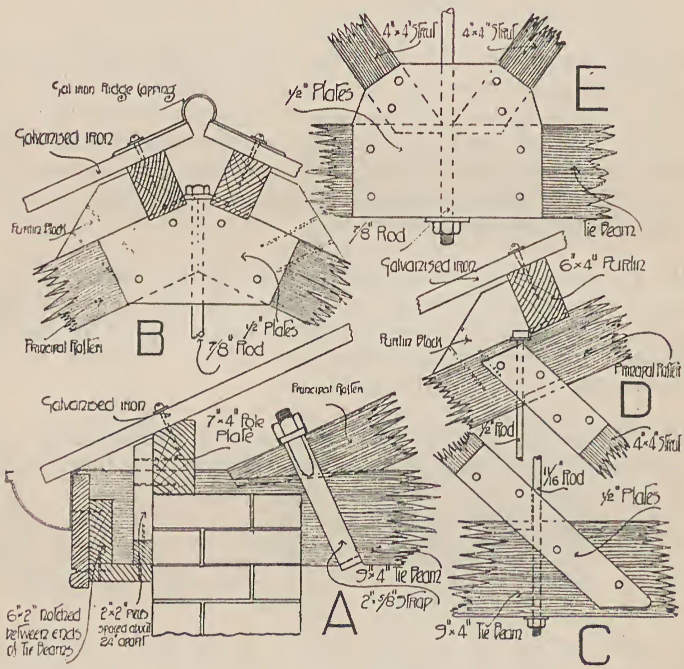


Fig. 148

therefore reduced to 8 x 4 or 32 sq. inches. A further reduction of 1 in. x 1·5 in., or 1·5 sq. inch is made for the tenon of the principal rafter, so that 32 — 1·5 = 30·5 sq. inches of timber left in the section, which is just a little in excess of the 29·8 sq. inches required by the computation made above. The 9 in. x 4 in. section will also be found sufficient at any other place where holes or cuts are made. Take, for instance, the section at the centre where the central tension rod passes through. A hole 1 in. diameter would have to be made for this rod. Nine inches of area would therefore be lost, so that the full section,

$9 \times 4 = 36$ sq. inches, would be minus 9, leaving 27 sq. inches. The tenons of the struts would be 1 inch wide, so that nothing would be lost, the bolt already having destroyed the central vertical 1 inch layer of fibres. The stress at this section is not as great as at the end. From the diagram of stresses it will be found to be 10,000 lbs.

$$\text{Then } \frac{10{,}000}{570} = 17{\cdot}5 \text{ sq. inches.}$$

as the area required, which will be much exceeded by the area of the timber left at that section, which has been found to be 27 sq. inches.

645. The principal rafter must be the same thickness as the tie-beam, namely: 4 ins. The depth for practical purposes in handling during construction and other reasons can hardly be less than 6 inches. Each principal rafter will be in one piece of timber, yet for purposes of calculation, it must be considered as divided by the ends of the struts into a number of short compression members. Enough of cross section must be provided to resist the stress in that part having the greatest stress. The lower division named, 1 - 9, will have the greatest stress. This length must be calculated as a post or strut. The length $= 82{\cdot}5$ inches, section $= 6$ in. $\times$ 4 in., area $= 24$ sq. inches, safe stress for oregon $= 1{,}425$ lbs. per sq. inch. Using the formula, Art. 608, *ante,* the safe load will be—

$$= \frac{24 \times 1{,}425}{1 + \dfrac{82{\cdot}5^2}{1{,}100 \times 4^2}} = 24{,}662 \text{ lbs.}$$

The member is to stand a stress of 16,000 lbs., so that there is abundance of strength. However, as pointed out, it would be unwise to make it less for the reason given.

646. The longest strut is that named 18 - 12. This member has a length of 126 inches. As pointed out, 608 *ante,* it is bad practice to make the length of posts more than 30 times the least dimension of cross section. This being the case, we cannot use less than a 4 in. x 4 in. cross section. Indeed, 4 in. is a little shorter than what is required since $\frac{126}{4} = 31{\cdot}5$. It is, however, all right provided we do not load it up to the amount given by the formula.

Applying the formula—

$$\frac{16 \times 1{,}425}{1 + \dfrac{126^2}{1{,}100 \times 4^2}} = 11{,}987 \text{ lbs.}$$

The strut has to stand only 5,900 lbs., so that it will be strong enough.

647. The other two struts, 17 - 11 and 9 - 10, by calculation, would have smaller cross sections. There are, however, reasons such as fixing the ends, why it will be better to make them also 4 in. x 4 in. Very little extra weight on the truss will result, and the cost would be trifling. The student may, however by applying the formula, determine the least cross section that will suit. The Fig. 148 shows the methods of jointing the various members together. It will be seen by sketches C D and E, that half-inch plates are placed on each side joints of struts with tie beam and principal rafter. This has been done to provide good fixing for ends of struts, and also to relieve the tension rods of the side thrust from the struts, which would occur in all cases but that of the bottom of the central tension rod.

648. The strap holding the joint of the tie-beam with principal rafter is an important practical part of the truss. The principal rafter is made to toe into the tie beam, so as to prevent it sliding along. As a matter of fact, very little reliance can be placed on this joint, and a sufficiently strong steel strap is usually put on to hold the joint.

649. The diagram to determine the stress is given in Fig. 149. A B is drawn parallel to the principal rafter. On this line is set out to scale the stress on the lower part of the principal rafter. In this case the stress is 16,000 lbs. AB will, therefore, represent to scale this amount of 16,000 lbs. From B drop a perpendicular to the tie beam. Then draw a line from A perpendicular to AB to cut the line from B at the point C. AC will then represent to the same scale as AB, the stress in the strap. In this case it is 33,750 lbs. The strap will be made of steel, with a safe strength of 18,000 lbs. per sq. inch in tension.

The total cross section of the two sides of strap will be:—

$$= \frac{33{,}750}{18{,}000} = 1{\cdot}87 \text{ sq. inches.}$$

The area of strap on each side will be:—

$$\frac{1{\cdot}87}{2} = 0{\cdot}935 \text{ sq. inches.}$$

The strength will depend on the two bolt ends, so that the diameter of these may be determined first. Each must have

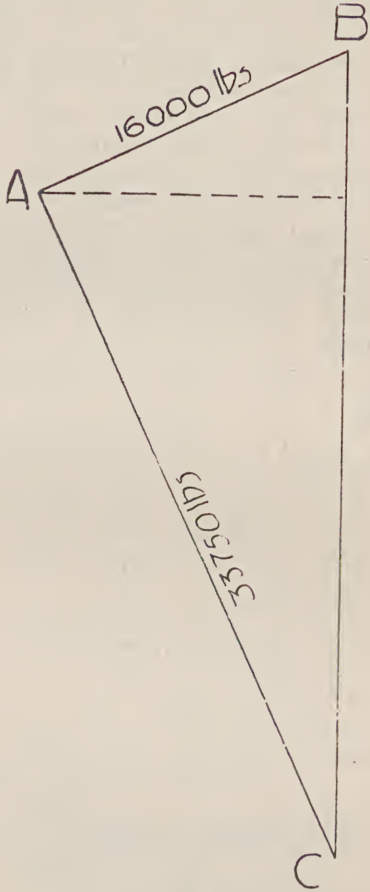


FIG. 149

an area inside the threads of 0·935 sq. inches. The diameter of a circle having the area will be 1·16 approx. This will be the value D in the formula. (See Art. 641, *ante.*)

$$\text{Then } d = \frac{1 \cdot 16 + \cdot 06}{\cdot 9} = 1 \cdot 35 \text{ in.}$$

which will be the diameter of the bolt end before screwing.

The sides of the straps may be 2 in. x 9-16 in., which contain sectional area of 1·12 sq. inch. This is just a little too strong, but quite near enough. In the sketch (Fig. 148)

various details of purlins, pole plate, eaves, etc., are given, so as to complete the drawing. Many of the details could, of course, be varied, provided the cross sectional areas of the members of the truss and their joints be not diminished.

650. Sizes of Sections for Steel Truss of 50 feet Span. It will now be necessary, as an example, to calculate the sizes of the various members for a steel construction to suit the truss, a stress diagram of which was prepared and shown by Fig. 146, and for which sections for a composite timber and steel construction have just been calculated.

651. Design of Steel Members in Compression. Commence first with bar 1 - 9 which according to the table in Art. 638 *ante*, bears a compression of 16,000 lbs. To find a suitable section trials must be made. In this example 2 — $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. L_s will be tried.

Properties of 1 — $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. L are

$$I = \cdot 385$$
$$A = 1{\cdot}06.$$

As there are two I will be ·770 and A — 2·12

$$r = \sqrt{\frac{I}{A}}$$
$$= \sqrt{\frac{\cdot 770}{2{\cdot}12}}$$
$$= \cdot 678.$$

Using the formula $f = 18{,}000 - 80\,\frac{1}{r}$ for allowable stress

$$f = 18{,}000 - 80 \times \frac{82{\cdot}5}{\cdot 678}$$
$$= 8271{\cdot}6 \text{ lbs.}$$

The area is 2·12 sq. ins., therefore the allowable load on the two L^s will be—

$$2{\cdot}12 \times 8271{\cdot}6$$
$$= 17535{\cdot}792 \text{ lbs.}$$

As the stress in the member is only 16,000 lbs. the section is satisfactory.

Note. If the section had not proven satisfactory other sections would have been selected and tried out.

All compression members are calculated in this way.

652. Design of Rivets to Compression Bar 1 - 9. The principal rafter or bar 1 - 9 will be securely fixed to the gusset plate

at the toe with rivets. The gusset plate will be $\frac{3}{8}$ in. thick. Using $\frac{3}{4}$ in. rivets and as the L^s are only $\frac{1}{4}$ in. thick the bearing will decide the number required.

The stress is 16,000 lbs. and the allowable bearing stress for $\frac{3}{4}$ in. rivets in a $\frac{1}{4}$ in. thick plate is 4,230 lbs.

Therefore number required will be—

$$\frac{16{,}000}{4{,}230} = 3{\cdot}07.$$

Say 4 rivets.

The number of rivets required for all compression joints are designed in this way.

653. Design of Steel Members in Tension. Take bar 21 - 9 which according to table in Art. 638 *ante,* which bears a tension of 17,000 lbs.

In tension members the loss of area due to rivet holes must be deducted.

Take two $2\frac{1}{2}$ in. $\times$ $2\frac{1}{2}$ in. $\times$ $\frac{1}{4}$ in. L_s for this example, and $\frac{3}{4}$ in. rivets for connections.

Note. Holes for $\frac{3}{4}$ in. rivets are drilled $\frac{7}{8}$ in. diam.

The loss of area $= 2 \times 0{\cdot}875 \times 0{\cdot}25 = 0{\cdot}4374$ sq. ins.

The cross section area of the two L^s is 2·12.

Therefore the nett area $= 2{\cdot}12 - 0{\cdot}4374$
$= 1{\cdot}6826$ sq. ins.

The allowable stress = 18,000 lbs. per sq. in.

Therefore the strength of the two L^s in tension
$= 18{,}000 \times 1{\cdot}6826$
$= 30286{\cdot}8$ lbs.

As the stress was 17,000 lbs. this section will be quite satisfactory. This section is really too large, but smaller sections would not be practicable.

654. Design of Rivets to Tension Bar 21 - 9. In the same way as for bar 1 - 9 this member will be secured to the gusset plate at the toe with rivets.

Take the gusset plate as before $\frac{3}{8}$ in. thick and using $\frac{3}{4}$ in. diam. rivets, the allowable bearing stress of the $\frac{3}{4}$ in. rivets in the $\frac{1}{4}$ in. L^s will decide the number required.

Stress in member = 17,000 lbs.

Allowable bearing stress of $\frac{3}{4}$ in. rivets in $\frac{1}{4}$ in. plate = 4,230 lbs.

Therefore number required will be—

$$\frac{17{,}000}{4230} = 4{\cdot}01$$

Say 5 rivets.

655. Details of Connections. Fig. 150 shows the connection of the various steel members at the bearing for the truss in Fig. 146.

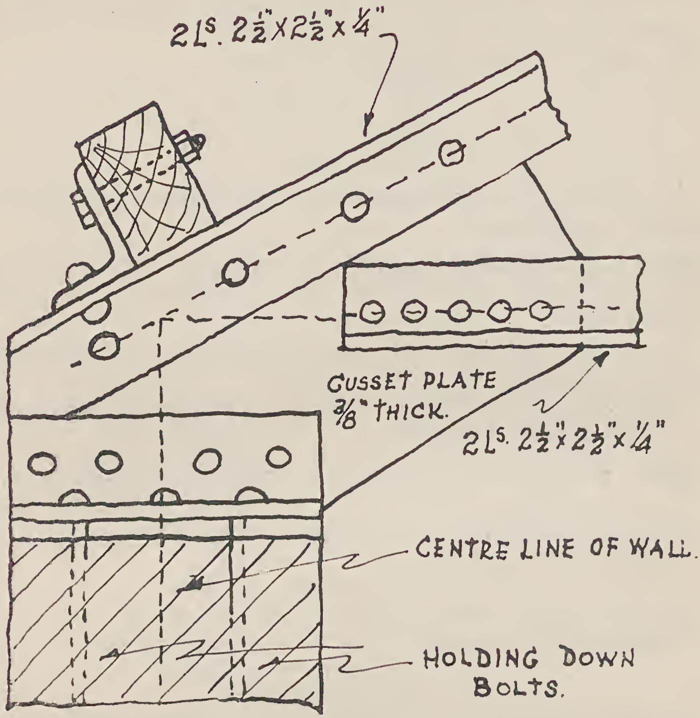


FIG. 150

Fig. 151 shows the connection of the steel members at the apex for the truss in Fig. 146.

655a. It should be noted that the joints of the members in a steel roof truss can be made with welds. The use of welding allows of smaller sections being utilised. This is so because there is no loss of cross section at the various joints as is the case when rivets are used.

656. Steel roofs of large Span. In the design and construction of steel roofs of large span, special provision must be made for expansion and contraction of the metal. This is effected by allowing one end of the truss freedom to move on its bearing. For such cases the stress diagram will be somewhat different to the diagram described in these articles. Provision for expansion and contraction will not, however, be necessary for roofs of less than 85 feet of span.

657. **Braced Girders.** These girders are useful for many purposes in building construction. They are, however, deficient in stiffness, so that they cannot take the place of the plate web girders, described in Chapter X, for carrying walls. Fig. 152 shows a form of braced truss known as a warren girder. It

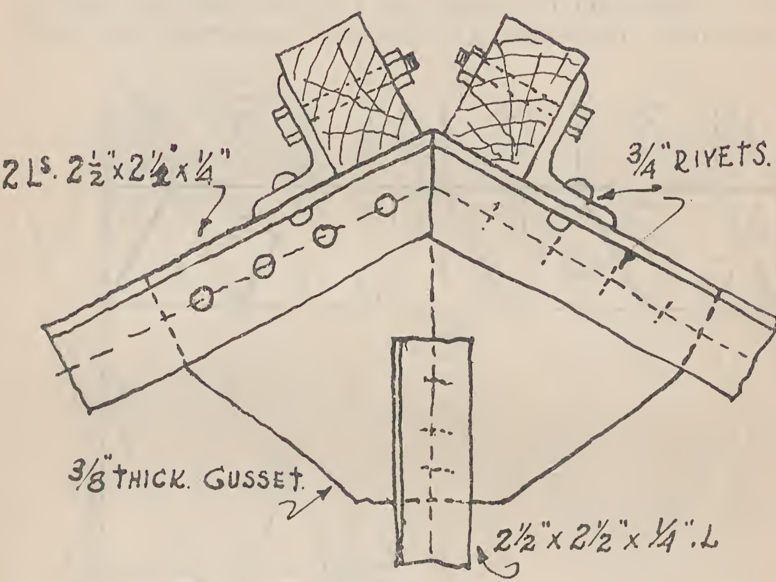


FIG. 151

consists of top and bottom flanges, braced with diagonals of which some are in tension and others in compression. The stresses are determined in the same way as described for roof trusses. The girder shown by sketch, Fig. 152, supports seven loads, of which two are at the ends over the piers. The loads named by the figures at each side of them are set to scale on a vertical line XY. From the loads on this line various lines are drawn parallel to the different members of the girder, just as would be done in the case of a roof stress diagram. The members in compression are shown dark, and those in tension are shown light in the sketch of the girder. Fig. 153 shows a lattice girder, together with its stress diagram. Warren and lattice girders are built up of Ls rivetted together in the same way as similar members on roof trusses.

657a. **Timber Connectors.** Timber connectors are a recent

development in construction and are particularly applicable to joints in roof trusses.

There are two types available in Australia, namely, Alligator type indicated at A Fig. 153a and Split Ring type indicated at B Fig. 153a. Typical joints in a roof truss are shown in Fig. 153b.

It is important that particular attention should be paid to maintenance of trusses in which timber connectors are used,

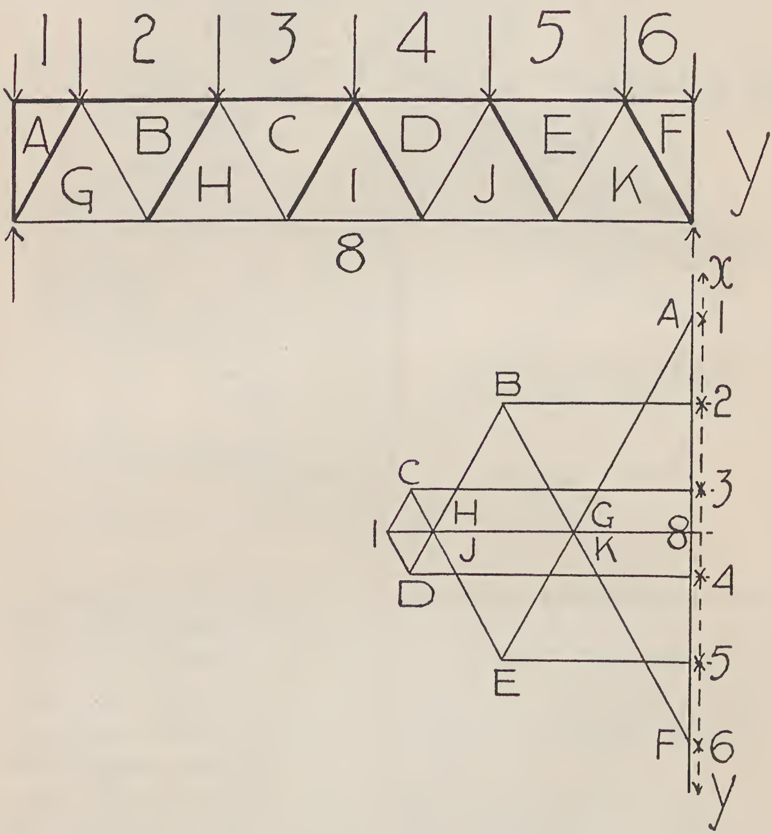


Fig. 152

as the efficiency of the connectors greatly depends on the bolts, which hold the joints together, being kept tight.

Complete information on the use of timber connectors under Australian conditions is not available, but further tests

are now being carried out. Such information as is available is given below.

(a) **Alligator Connectors.** Alligator connectors are embedded by pressure in the timbers forming the joint. The pressure is usually applied by tightening the bolts holding the joint together, but for large rings and hard timbers, suffi-

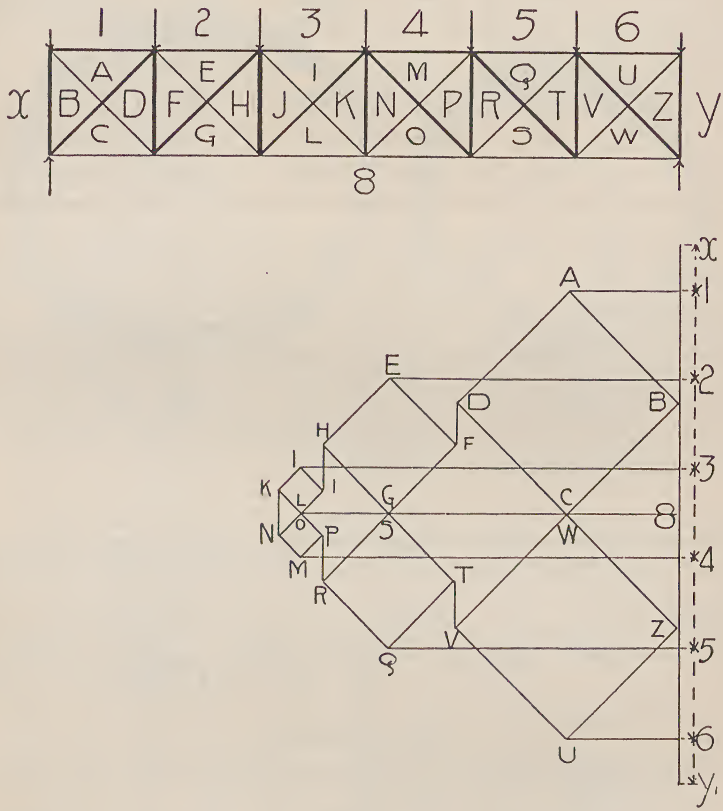


FIG. 153

cient pressure cannot be obtained by this means, and it becomes necessary to use high tensile steel bolts, ball-bearing thrust blocks, and oversize washers to fix the connectors, or make use of G clamps, and hydraulic jacks.

The permissible loads per connector recommended by the

United States Forest Products Laboratory for oregon where there is no decay hazard are as follows:—

TABLE XLV(A)

Diameter of Connector Inches	Minimum Diameter of Bolt Inches	PERMISSIBLE LOAD PER CONNECTOR—LB. Load Parallel to Grain: Green	Load Parallel to Grain: Less than 15% Moisture Content	Load Perpendicular to Grain: Green	Load Perpendicular to Grain: Less than 15% Moisture Content
2	½	700	1,100	500	830
2⅝	⅝	1,100	1,800	800	1,350
3⅜	¾	1,600	2,600	1,200	1,950
4	¾	1,900	3,200	1,400	2,350

If the load is applied at an angle θ to the grain, the permissible loads for values from $\theta = 45^\circ$ to 90° are the same as those for $\theta = 90^\circ$ (i.e., load perpendicular to grain); for values of θ between 0° and 45°, the permissible loads may be obtained by interpolation. Where there is a decay hazard, the above loads should be reduced by the factors given hereafter. Where there is more than one connector, the strength of the joint is directly proportional to the number of connectors. Other details are as follows:—

TABLE XLV(B)

Diameter of Ring Inches	Minimum Dimensions of Timber—Inches: Width	Thickness: Rings in one face only	Thickness: Rings in both faces	Minimum Ring Spacings of Margins—Inches: End Margin	Spacing C to C of Rings Parallel to Load	End Margin
2	2⅝	1 1/16	1⅝	2	3	1¼
2⅝	3⅝	1 1/16	1⅝	2⅝	4	1¾
3⅜	4⅝	1 1/16	1⅝	3⅜	5	2¼
4	5½	1 1/16	1⅝	4	6	2¾

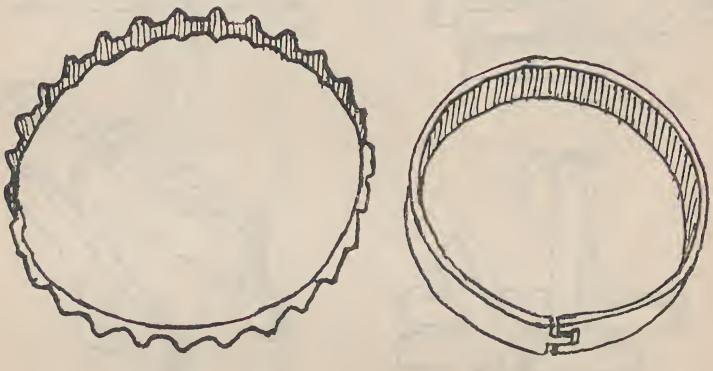
The end and edge margins are the distances from the centre line of the bolt to the end and side of the piece respectively.

(b) **Split Ring Connectors.** Split ring connectors are fitted into pre-cut grooves in the pieces of timber to be joined. The grooves are cut with a special tool and are made slightly

Tables XLV(A) and XLV(B) from C.S.I.R. Handbook.

larger in diameter than the rings. When assembling the joint the split in the ring should be fixed nearest the edge of the timber stressed parallel with the grain.

Tests now in progress indicate that the following working loads indicated in table are safe for joints made in timber where there is no decay hazard.



A. B.

FIG. 153A

Where the timber is completely protected from the weather there is said to be no decay hazard. Where the timber is exposed to the weather the following loads should be reduced from 0·95 to 0·75, depending upon the grade of timber used and the weather conditions prevailing. If the grade of timber used is very poor and the weather extremely bad the loads should be reduced by 0·50.

TABLE XLV(c)

Inside Diam. of Connector Inches	Width of Connector Inches	Thickness of Connector Inches	Diam. of Bolt Inches	Permissible Load Per Connector—Lbs.					
				Ironbark		Tallow and Jarrah		Oregon	
				Load Parallel to the Grain	Load Perpendicular to the Grain	Load Parallel to the Grain	Load Perpendicular to the Grain	Load Parallel to the Grain	Load Perpendicular to the Grain
2½	¾	⅛	½	4,000	1,500	3,000	1,000	2,500	1,000
4	1	3/16	¾	6,000	3,000	5,500	2,000	5,000	2,000

Table XLV(C) from C.S.I.R. Handbook.

The strength of a joint in which there are more than one connection is directly proportional to the number used.

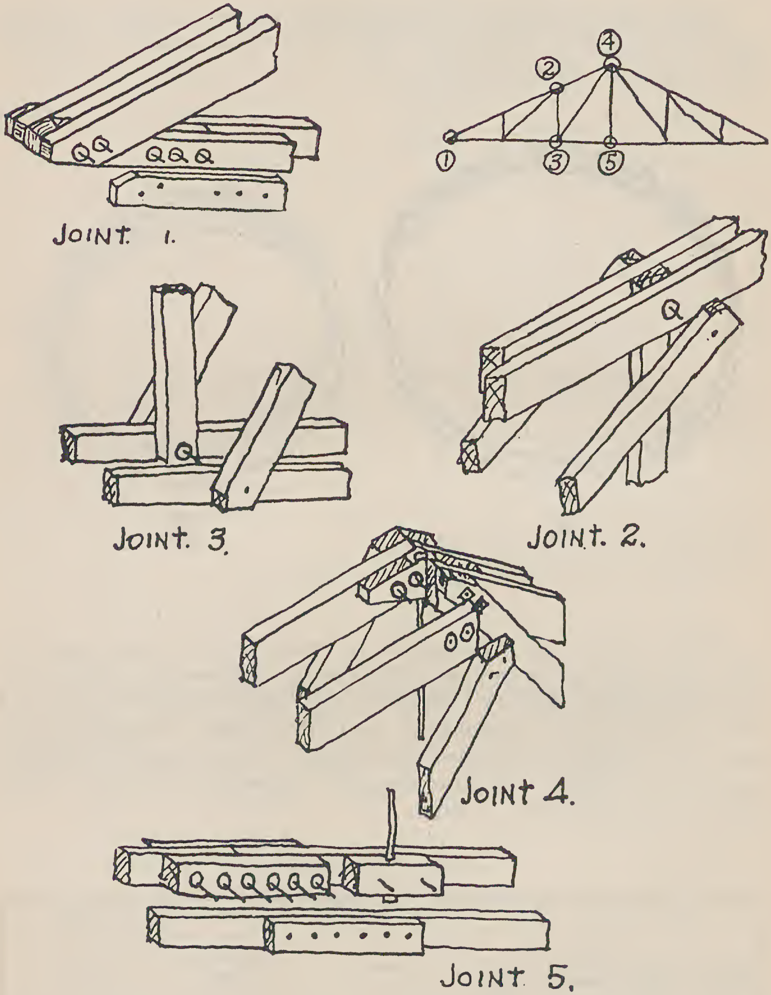


FIG. 153B

TABLE XLV(D)

Diam. of Connector	Minimum Dimensions of Timber—Inches			Groove Dimensions Inches			Minimum Ring Spacing—Inches			Minimum Dimension of Washers Inches
	Width	Thickness		Inside Diam. of Groove	Width of Groove	Depth of Groove	End Margin	Spacing C. to C.	End Margin	
		Rings in one face	Rings in opposite faces							
2½	3⅝	1 5/16	1⅞	2·56	0·15	0·39	3¾	3¾	1¾	2x2x⅛
4	5½	1⅝	2⅝	4·08	0·21	0·52	6	6	2¾	3x3x3/16
6	7½	2⅛	3⅝	6·12	0·27	0·65	9	9	3¾	3x3x¼
8	9½	2⅝	4½	8·14	0·34	0·78	12	12	4¾	3½x3½x⅜

Table XLV(D) from C.S.I.R. Handbook.

CHAPTER XII

ARCHES, BUTTRESSES, AND RETAINING WALLS

658. The Calculations Necessary to arrive at the strength of arches are of a very abstruse and complicated nature, and quite beyond the scope of this book. A graphic method which gives results on the safe side may, however, be easily understood, and will be of interest and value to the student.

Fig. 154 shows the half of an arch and its load. Without the other half this portion would immediately turn inwards about the point P. Strictly speaking, however, it would be considered to turn not on P, but on the point A, some little distance in from the outer point P. This is a practical provision, for crushing would occur at P, and actual turning would take place as described at the point A, which is safely placed at $\frac{1}{4}$ the width of arch ring in from P. The turning of the half arch and its load, as shown in the sketch, will, therefore, be taken as about the point A. Its tendency to turn about A would be its moment about A. The moment would be its weight acting through its centre of gravity, multiplied by the distance of its line of action from A. We will assume that the weight of the half arch and its load is represented by W. This weight would act through the centre of gravity, marked CG on the showing. The distance of the line of action through CG from A is marked a on the drawing.

The moment of turning about A would therefore be Wa. Now, since the other half of the arch is to provide a thrust H to hold this half up, and since this thrust must have an equal and opposite moment about A, it will be possible to determine the amount of this thrust, H, if we knew its leverage. The thrust must act somewhere within the middle half of the arch ring at its upper portion. It has been marked at the upper point of the middle half of the arch ring on the sketch, and denoted by H; it will have a horizontal direction, and, indeed, is known as the *horizontal thrust*. The perpendicular distance of the horizontal thrust from A is marked h on the sketch. The moment of this horizontal thrust about A will therefore be Hh. We may now assume that the other half of the arch is restored, and that it gives the horizontal thrust H to hold up the half shown in the sketch. If the arch be safe, the moment of turning inwards of the half arch must be equalled by the opposite moment of this horizontal thrust of the other half, or

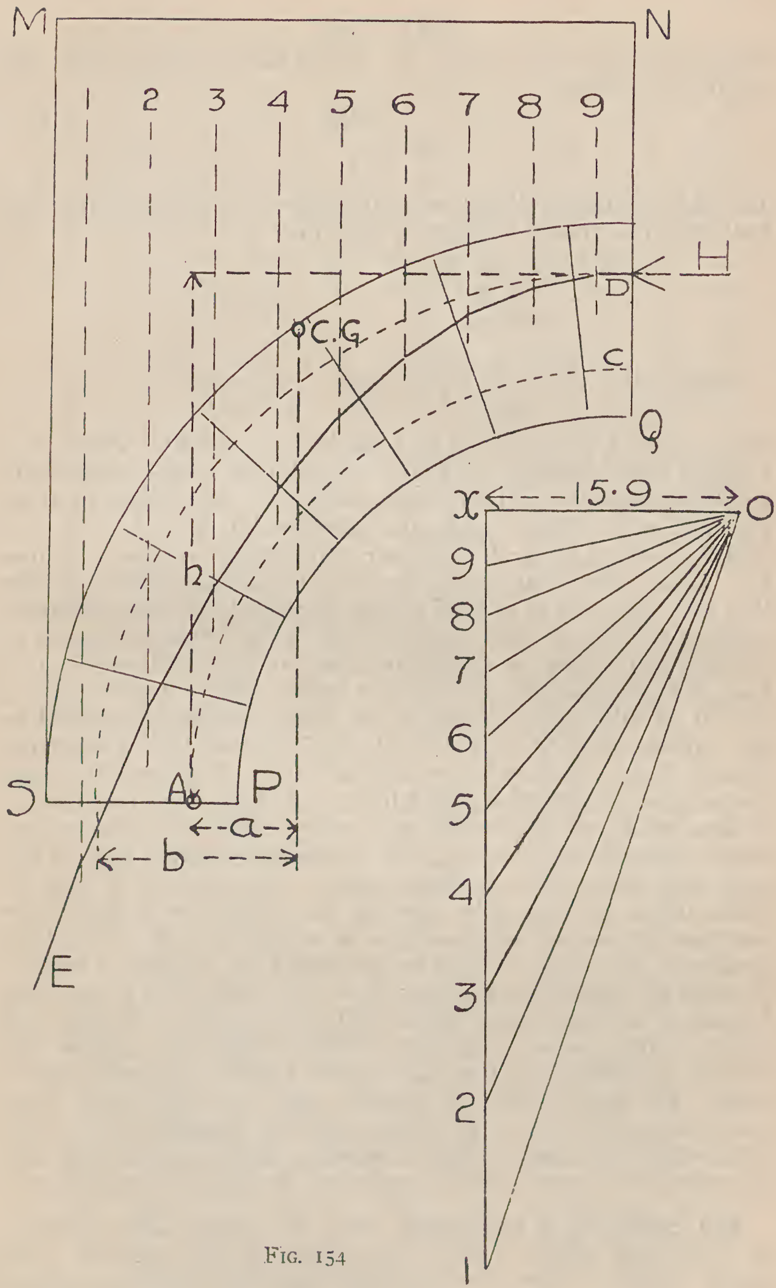


FIG. 154

$$Hh = Wa.$$

Now if we know h, a, and W, it will be possible to find the value of H, since

$$H = \frac{Wa}{h}$$

Let the following distances and heights be assumed for the half arch illustrated by sketch, Fig. 154.

$$W = 81{\cdot}52 \text{ lbs.}$$
$$a = 1{\cdot}6 \text{ ft.}$$
$$h = 8{\cdot}2 \text{ ft.}$$

$$\text{Then } H = \frac{81{\cdot}52 \times 1{\cdot}6}{8{\cdot}2} = 15{\cdot}9$$

This value of H is set out to scale by the line XO. From X a vertical line is drawn, and on it are plotted to the same scale as H the amounts of the various loads per foot of the weight on the half arch. These loads are numbered 1, 2, 3, 4, 5, 6, 7, 8 and 9 on the half arch and correspondingly on the load line 1X. Lines from O are then shown to the various points on the line 1X. The line H is then drawn parallel to xo and produced to meet the line of load 9 on the half arch. From this point of intersection a line is drawn parallel to O9 until the line of load 8 is intersected. From this latter intersection a line is drawn parallel to O8. And so on, lines are shown parallel to the various lines O7, O6, O5, O4, O3, O2 and O1 to meet the lines 7, 6, 5, 4, 3, 2 and 1 on the half arch. A curve DE, composed of a number of straight lines, called the *line of resistance,* is thus produced on the half arch ring. This line of resistance must, throughout its length, be within the middle half of the arch ring shown by the dotted lines. The value of H may be increased or decreased by varying the lengths of a and h; for instance, it may be increased by lowering the line of H, thus making h less, and it may be increased by making a longer. It must be noted that any position of H from D to C, and any lengths of a from a to b, which will give a value of H that will allow of the line of resistance falling within the middle half will be permissible. If none of these values will give such a result, the arch would be unsafe, and the ring would have to be widened. It will be noted that the triangles OX9, O98, O87, etc., are really force triangles, each determining the direction of its corresponding portion of the line of resistance.

659. Strength of Buttresses. Fig. 155 shows side elevation of a buttress with a thrust PA applied at the point X. The thrust tends to turn the buttress outwards about the outer

point C of the middle half of the lower portion. This moment of turning outwards will be the force of thrust PA multiplied by the perpendicular distance BC of the point C from the line of force PA. For example, let PA = 5,188 lbs., and BE 6·5 ft.

The moment of PA will therefore be 5,188 × 6·5 = 33,722 ft. lbs. This moment must be opposed, and at least equalled by the moment of the force due to the weight of the buttress to turn round the point C. The total height of the buttress if of brickwork would be 24,090 lbs., taking the weight of brickwork at 150 lbs. per cubic foot. This weight would act along a line AD, passing through the centre of gravity of the whole buttress. The distance of this line of action from the point C would be 1·4 ft., which would be the leverage of the weight of the buttress in its action about C. The moment of resistance to turning of the buttress would therefore be

24,090 x 1·4 = 33,726 ft. lbs.

which is a few pounds greater than the moment of turning. The buttress would therefore be safe.

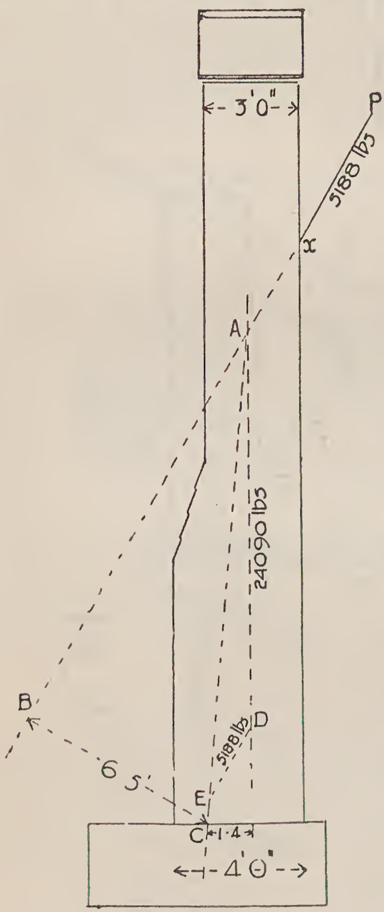


FIG. 155

An alternative method on the principle of the triangle of forces may be used as follows: Produce the line of thrust of PA until it cuts the line passing through the centre of gravity. Set out to scale AD the total weight, 24,090 lbs., of the buttress. From D draw a line parallel to PA, and make it equal to PA, namely 5,188 lbs. Join the end E of this line with A. Then AE will be the resultant of the two forces PA and AD. This resultant, if produced, must pass within the middle half of the lower portion of the buttress. In the example it just passes at the right-hand extremity of the middle half.

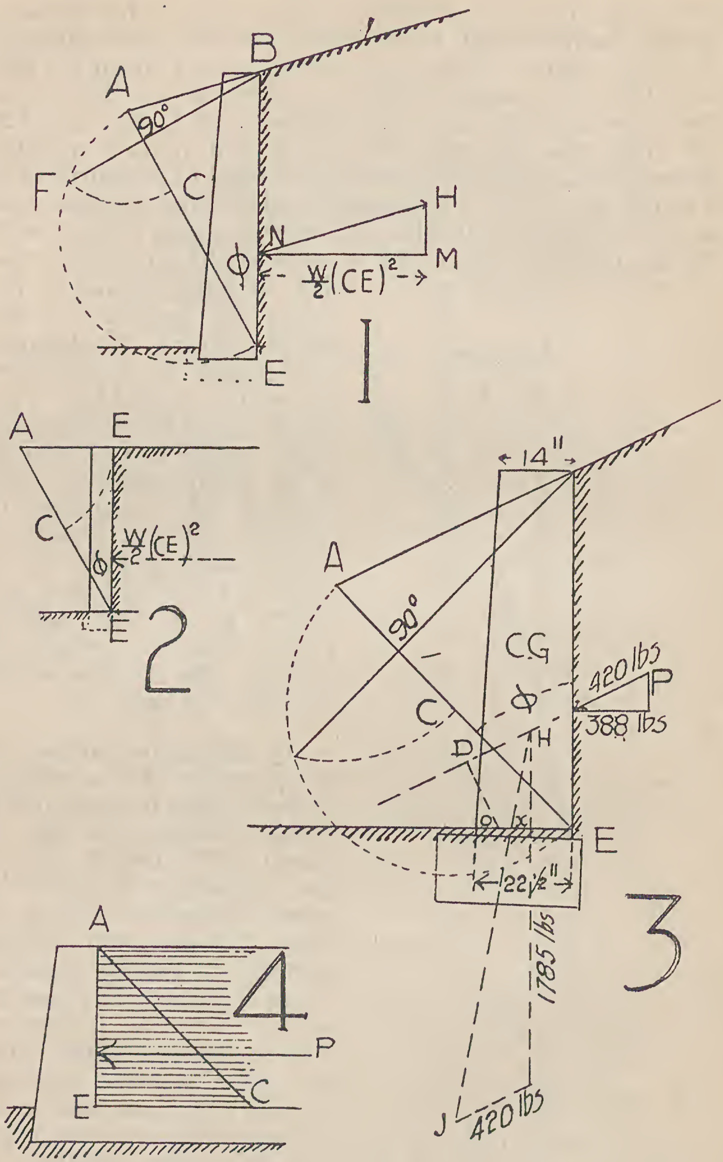


FIG. 156

660. Retaining Walls. A bank of earth or clay, or other loose material, if formed with a vertical face, would soon fall away and form a sloping surface. Each kind of material has

its own particular slope or *angle of repose,* as it is called lower than which it will not further slip. A wall to retain or hold a bank of sand, earth or clay, must therefore be strong enough to keep the wedge-shaped sliding portion in position. This wedge of material acts through a line at a point $\frac{1}{3}$ of the height of the retaining wall from the bottom thereof. The effect of the wedge along this line may be calculated as follows:—Let the line BE, sketch I, Fig. 156, represent the back of a retaining wall. From the bottom of this line set up a line AE, making an angle equal to the angle of repose of the material to be retained. Produce the line of slope of the upper surface of the bank to meet AE at A. Bisect AE and describe a semicircle on it. From B draw a line perpendicular to AE, until it meets the semicircle at F. With A as a centre, and AF as radius, describe an arc to cut AE at C. Measure the amount of CE.

Then the horizontal component of the pressure of the wedge of earth at a point $\frac{1}{3}$ of BE will be:—

$$\frac{W}{2}\left(CE\right)^2$$

in which W equals the weight of a cubic foot in lbs. of the earth to be retained. The result of the calculations will be in lbs. This result is to be set out to scale NM, as shown. From the point of application draw a line parallel to the slope of top of bank. Cut this line at H by a perpendicular from M. The line NH will be magnitude and direction of earth pressure on wall. Sketch 2, Fig. 156, shows the modification necessary when the top of bank is level. Sketch 3, Fig. 156, shows an application of the method to a wall 7 ft. high to retain clay with an angle of repose of $\Phi = 45°$, and a weight per cubic foot of 135 lbs. CE measured from the drawing equals 2·4 ft. Then

$$\frac{135}{2}\left(2{\cdot}4\right)^2 = 388{\cdot}8 \text{ lbs.}$$

is the horizontal component of the clay pressure at $\frac{1}{3}$ of the height of wall. The pressure parallel to slope of top of wall will be 420 lbs., found by drawing as above described. This pressure will have an overturning effect at O, the outer extremity of the middle half of lower part of wall. The moment will be

$$= 420 \text{ lbs.} \times DO = 420 \times 1{\cdot}5 = 630 \text{ ft. lbs.}$$

The weight of a wall, 7 ft. high, 22½ inches at bottom, and 14 inches at top, will be 1,785 lbs. This weight will act vertically downwards through the C.G. of the wall. The dis-

tance of the line of action of this force from O = ·65 ft., so that its moment about O will be

$$= \cdot 65 \times 1{,}785 = 1{,}160 \text{ ft. lbs.}$$

This is much more than the moment due to the earth pressure. A reduction of 4½ inches of thickness of the wall would, however, make it too light, so that the above size would remain.

An alternative method by the triangle of forces is shown on the sketch. The line of pressure PD intersects the line of weight of the wall at H. From H set out the weight of wall 1,785 lbs. to scale. From the bottom of this amount draw a line parallel and equal to earth pressure; join the end J of this line with H. Then JH will be the resultant of the earth pressure and weight of wall. This resultant must pass through the middle half of the lower portion of the wall, which it does, as shown by the sketch.

The material retained by walls should be well drained, otherwise the angle of repose calculated upon will be lowered, and the estimated strength of wall will be exceeded.

661. Small Dams. The calculations for walls or dams to retain water are much more simple than for those to retain earth or such material. At any rate, such is the case with small dams.

The sketch 4, Fig. 156, shows a section of a small dam. The pressure at the back AE of the wall is proportional to the height, and is perpendicular to the back of the wall. The line EC is equal to AE; join AC, then the triangle represents the pressure at back of wall. The pressure will act through the centre of gravity of the triangle, as shown by the line P. To determine the pressure along P, it will be necessary to find the weight of a triangle equal to AEC of water 1 foot thick. Find the ⅓ of AE. Then the pressure of the weight of the one foot thick triangle of water will act at this point. A piece of the wall 1 foot long must then be designed to resist the pressure.

TABLE XLVI

Angles of Repose of Various Materials.

Kind of Material	Angle of Repose in Degrees
Sand	25
Earth	30
Clay (well drained)	45
Gravel	48

CHAPTER XIII

SHORING AND UNDER-PINNING

662. The Operation of Shoring up, or under-pinning a structure, is one that is frequently met with in practice, and it is not by any means among the least important of the many matters which, during building erection, require the exercise of the judgment and skill of the supervising architect and builder.

663. Raking Shores. The inclined prop or support to hold up the wall of a building is called a raking shore. One of these

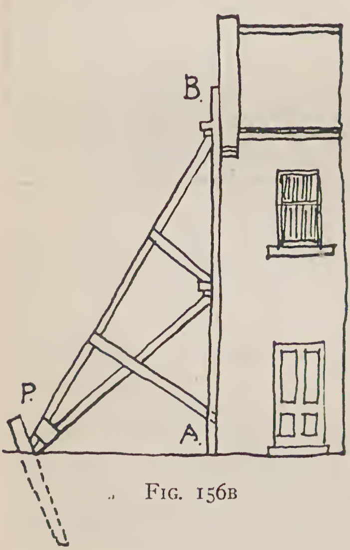


FIG. 156B

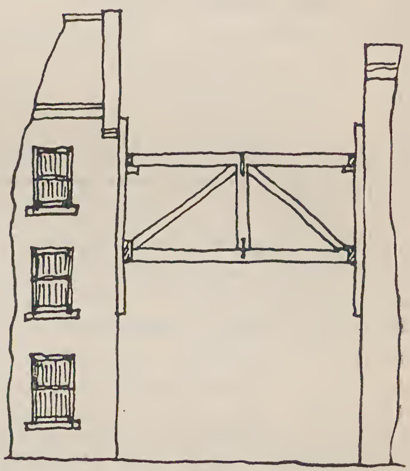


FIG. 156C

shores is generally allowed for each story in the building to be shored up, and they are arranged one above the other in groups, which are about 15 feet apart. An upright piece of timber called a *wall piece* is placed against the wall to receive the heads of the shores in each group. Connection between each shore and wall pieces should be made by mortising the wall piece and inserting therein a piece of timber called a *needle*, the outward projection of which forms the abutment for the top or head of the shore. Of course care must be exer-

cised that the needle, in any case, is strong enough to resist cross breaking by the upward pressure of the shore. The piece of timber against which the bottom ends of the shores abut is called the *sole piece*, and its solid and secure foundation, in any case, is a matter of the greatest importance. Pieces of timber are used crosswise to brace the shores in each group together, and they should be connected to the shore with bolts. See Fig. 156 B.

664. Sizes of Timbers for Shores. The following table of scantlings for raking-shores in cases of shoring adjacent but sound buildings against accident during excavation, etc., will be found useful.

TABLE XLVI(A)

Sizes of Scantlings for Oregon Pine Raking Shoring Timbers.

Height of Wall to be Shored	Cross-section of Raking Shore
15 to 20 feet	6in. x 4in.
20 ,, 30 ,,	9in. x 4in.
30 ,, 40 ,,	10in. x 5in.
40 ,, 50 ,,	12in. x 6in.
50 ,, 60 ,,	12in. x 8in.

Angle of inclination about 60°.

665. Flying Shore is the name given to a shore which acts horizontally between the two structures to be shored up. For example take two houses, separated by about 30 feet, and between which a new building is to be erected. During the excavation work it will be necessary to shore the two against accident and collapse, and this may be accomplished by arranging the shores, not raking, but horizontally between the two buildings, so that each shore abuts against one as well as the other. For the sake of stiffness and prevention of "sagging" the shores in each group are strutted and braced together, much on the same principle as a roof truss. See Fig. 156 C.

666. Vertical Shores are those used to support a wall, or part thereof, independently of foundations, during alterations such as making of openings and so on, or while repairs are being made, or sometimes while new foundations are being built in. A case of common occurrence is when an opening, for a shop front or some such purpose, has to be made in an existing wall. The space above where the opening is to be, is first made secure against collapse by being temporarily supported or under-pinned by small "small beams" or "needles,"

which are themselves supported by strong upright timbers or columns. A longitudinal opening is then made, and either the permanent supporting arch or girder, as the case may be, inserted. The wall above the arch or girder is then made good, so that the weight of the upper part of the wall may be considered as fully resting on the arch or girder and permanently supported. To be successful it will be necessary to see that the making good above the arch or girder is solid and tight, and that the arch is firmly supported as the skewback, or that the girder, if such be used, is securely bedded at the bearings.

The next step will be to make the desired opening in the wall by removing that portion which is between the supports of the arch or girder and making good the jambs.

667. Under-Pinning is the term applied to the process of building new supports or foundations in under the piers or walls of an existing building. When the excavations for the basement of a building to be erected will descend to a level below that of the bearing of the footings of an adjacent building, right up against which it is intended to build, it becomes necessary, unless the nature of the foundation be of an unyielding character such as rock, to ensure the safety of the existing structure by building in under its footings a foundation wall which will reach down to the level of the foundations of the new building. The necessity for so doing will be obvious, for if the excavations were carried right up to the boundary the material (if it be clay or such like) composing the building site will crumble and fall in, causing collapse of the building wall resting on it. The troublesome and exceedingly hazardous work of under-pinning may be accomplished by proceeding as described in the following article, provided that the natural foundation is of a fairly stiff and reliable character.

668. Under-Pinning of a Wall rendered necessary by excavation for basement of new building. The excavation for the basement is commenced in the middle of the site, and carried down to the desired level and towards the adjoining building until within about 12 ft. thereof, so that a strip of land of that width is left completely along the foundation. Twelve feet as the width of such a strip is mentioned, but, of course, circumstances will alter the allowance such as, for instance, where the building is very high, or where the natural formation of the site has a tendency to be soft, the strip left must be much wider than if the natural foundation is good, or the building comparatively low. In any case it will be necessary to have plenty of allowance on the side of safety. The side wall of the adjacent building is then well propped up with

raking shores. A small cutting is next made through the strip of sustaining earth at right angles to, and running in under the foundation of wall, and in the opening so made is built a vertical strip of new foundation wall, the joint of top of which, with bottom of existing wall, is packed tight, to ensure a full and secure bearing. Another cutting is made some distance ahead and another strip of foundation wall built in the same manner, and so on at intervals until the whole of the wall rests securely on vertical sections of the under-pinning. The intervening masses of earth are then removed, and the vertical strips connected with walling of similar character. The under-pinning is generally executed in brickwork which requires that great care shall be taken to have the course in the various strips, on the same level, and the bond properly set out in each, so that when the intervening spaces are built in, there shall be perfect continuity of the *courses* and *bond*. See Fig. 156 D.

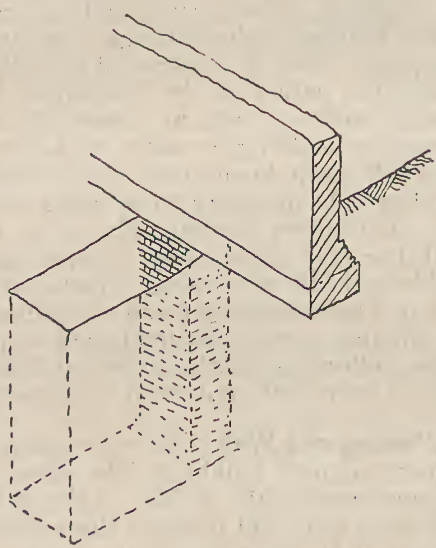


FIG. 156D

669. Under-Pinning should always be built in Portland Cement Mortar, and the building of it should not be too fast, so that the settlement, whatever there may be, in itself, may take place prior to the imposition of the weight of the wall.

670. Under-Pinning in Bad Foundations. In the event of the material of the site being sand or some such material of little lateral stiffness, it will be impossible to commence ex-

cavating the site before the completion of the work of under-pinning. After first shoring up the wall, the next thing to do will be to sink a vertical shaft to the level of the proposed bottom of the new foundation wall. Working in this

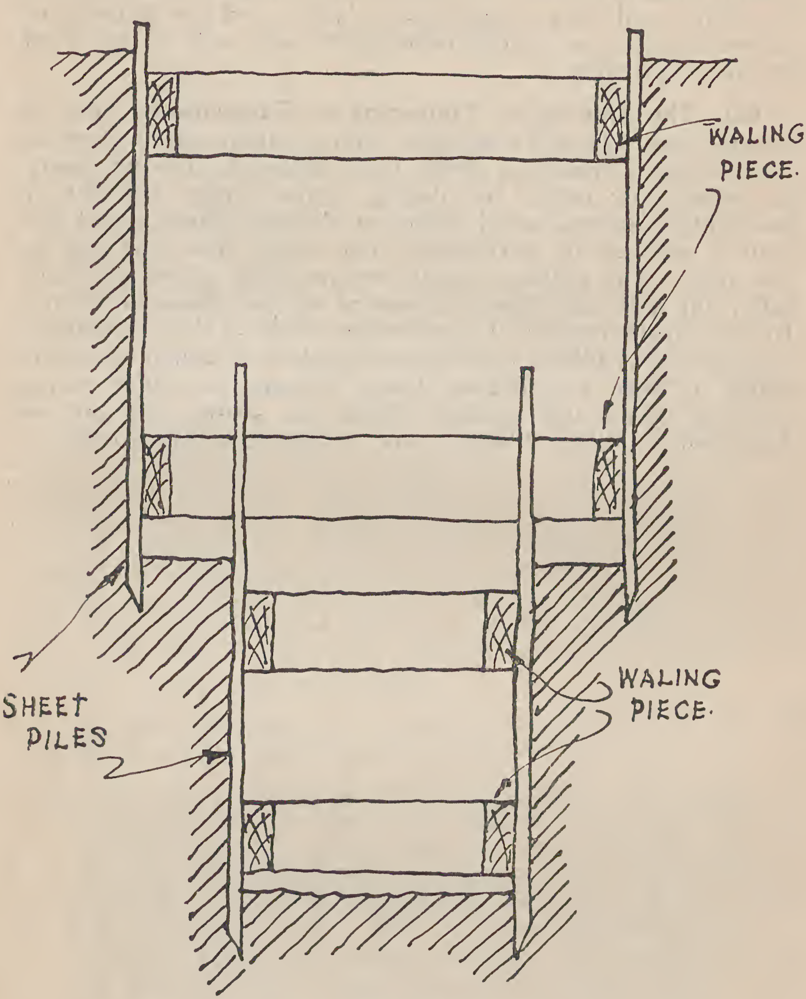


Fig. 156E

shaft, it will be possible to excavate a space under the wall, and so make room for the building in, of a vertical strip of, or section of the new foundation wall. Similar shafts are then sunk at intervals along the wall, but it will be noted that a

fresh shaft is not commenced until the strip is built in, and packed up from the last one. The strips are connected by removing the intervening materials, and building in the intervening lengths of wall. Of course the material at the sides of the shafts will have a tendency to fall in, and the methods of preventing this, as applied to all such cases, will be described in the next article.

671. The Shoring or Timbering of Excavations, such as Shafts, Trenches, and Cuttings. To prevent the earth, forming the sides of a trench or shaft, from falling it, it is necessary to temporarily retain by placing against them, upright or horizontal timbers, called *polling* or *sheeting boards,* which are kept in position by horizontal cross struts, from one side to the other. The polling boards are generally placed horizontally, but it is sometimes convenient to have them vertically. In very loose material it is necessary to have the sheeting or polling boards placed quite close together, in which case it is usual to have longitudinal ledge timbers or *waling pieces* crossing them, and against which the struts will act, as described for Sheet Piling in Art. 10 *ante*. See Fig. 156 E.

CHAPTER XIV

FIRE RESISTING CONSTRUCTION

To deal satisfactorily with this subject would require space altogether beyond what is available within the limit of this book. The subject is, however, too important to allow of being quite neglected. A few hints, even if very brief, will be of value.

672. **Small Buildings.** The use of timber lining for ceilings and walls of even small dwelling houses should be avoided. Plaster or steel plates is much safer, as offering a little more resistance. In houses built of stud walls and external weatherboards the plaster or steel stamped plate linings is even a greater necessity than in the case of brick or masonry construction. Shingles on the roofs of any kind of building is a dangerous covering, since sparks from the chimneys may easily cause ignition. Attached houses should have party walls carried right up, and finished with parapets. All fire places should have ample hearths of stone, concrete, or brick. This applies especially to the laundry copper furnace, and kitchen fire place. Gas brackets should be placed in positions where they will be as distant as possible from lace curtains of windows, and curtains of beds.

673. **The Americans,** by whom the subject has had especial attention, divide the subject into three classes:—

(1) **First Class or Fire-Proof Construction.** This applies to buildings of a public or semi-public character, such as theatres, hotels, public halls, churches, block tenement houses, office buildings, and large commercial buildings. Buildings in this class must have the best protection from fire of outside origin. They must be specially planned to facilitate rapid sub-division internally into isolated spaces by automatically closing heavy timber doors covered with tinned iron plates. All stair and elevator well holes must be covered in with fire-resisting walls and also be fitted with automatically closing fire-proof doors. The construction must be such as to offer the best resistance to fire. Preferably the walls are to be of brick work, for it must be remembered that clay products are amongst the best fire-resisting materials. All steel stanchions and

girders must be protected with either terra cotta lumber blocks, steel lathing and plaster or concrete, the floors and roofs to be of arched terra cotta blocks or reinforced concrete. As far as possible the roofs are built the same as floors, or are covered with fire-resisting material. As little timber as possible is used, indeed it is really wonderful how little timber is used in a first-class fire-resisting building. All window frames, sashes, door frames, doors, and attached mouldings, are of steel. Not even the hand-rails of the stairs are of timber. A great source of danger from outside fire exists when ordinary glass is used for the windows. The glass bursts in the earliest stages of either inside or outside fire, and a rapid spread of the latter is allowed. In all the first-class buildings glass with embedded wire is used. This glass stands fire well, or at any rate holds it back for a while.

(2) **The second class is called Mill Construction.** This class includes factories and warehouses; all floors and roof timbers of, at least, 80 square inches in cross section; all flooring not less than 3½ in. thick; and all wooden columns not less than 100 square inches in cross section, sub-divided into easily isolated divisions; and all elevators and stairs closed in with materials of strong fire resistive power. Timber of heavy cross sectional area is remarkably slow burning. This is especially the case with the Australian hardwoods. An excellent illustration of its behaviour under the influence of severe fire was afforded in the case of a large fire in Sydney some years ago. The fire—which lasted for 2½ hours—occurred in a large building used as a sawmill and joinery works, in two stories, the upper one supported on 12 in. x 12 in. ironbark story posts or columns. One of the story posts was near to a saw bench of cast iron. The intensity of the heat may be estimated by the fact that the top of the saw bench was melted. The column was not greatly damaged by the fire, being charred for only one inch from the original surfaces and the inner portion was as good as ever, so that only a comparatively small percentage of the carrying power was lost. This test brings out vividly what has all along been the experience of firemen, and there can be no doubt that where the breaking strength will, under ordinary conditions, suit the requirements of loading, as in the case of floor supports in large buildings, and for supports of front walls of ordinary business premises, ironbark columns and girders are preferable to those of unprotected or imperfectly protected steel.

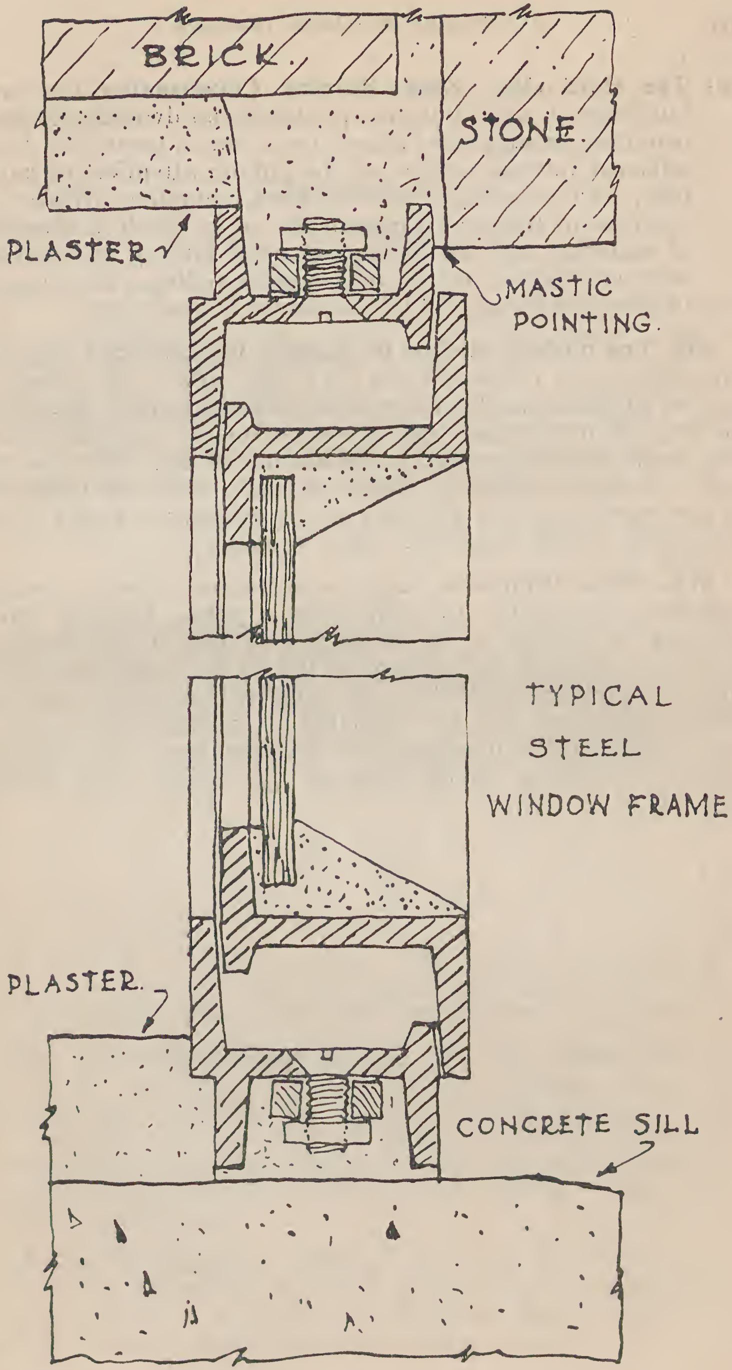

BRICK.
STONE.
PLASTER
MASTIC POINTING.
TYPICAL STEEL WINDOW FRAME
PLASTER.
CONCRETE SILL

FIG. 156A

(3) **The third class, Slow Burning Construction** for such buildings as small business premises and dwelling houses; provides, as suggested above, for as much protection from adjacent outside fire as can be got by attention to parapets, roof coverings, and windows, complete division in the case of terrace arrangements; of as much as possible of material such as plaster on metal lathing for ceilings and partitions, or metal coverings for ceilings; the absence of all wood lining and the enclosure of the stairs.

674. The modern method of building in reinforced concrete provides for fire resistance of a very high order. The construction of columns and floors by this method has been described in Arts. 77 to 93, *ante*, and needs no further comment here. The method of protecting stanchions and girders with concrete will be found satisfactory, provided that a sufficient thickness of concrete be put on all sides of the column or girder to be protected. A thin coating is next to useless.

674a. Metal Windows. Such are extensively used in present buildings, especially in commercial types. One of their greatest advantages is the small loss of light in the opening, due to the small metal sections of the frame. Steel and sometimes bronze are used for the construction of the frames. Many spray processes are available as an application against rust. Usually the windows are the casement type, or pivot hung, but are sometimes double hung as box frames. See sketch, Fig. 156a.

CHAPTER XV

ROOF PLUMBING

675. Materials. The materials used by the plumber are lead, galvanised iron, zinc, muntz metal, and copper. Tin is also used as a component part of solder.

676. Lead is one of the metals, and is prepared for the use of the plumber by being rolled into large sheets. These sheets vary in width and are 28 ft. to 30 ft. long. These are made into rolls, and supplied in that form to the plumber.

677. Lead is described by the weight per square foot, and is rolled in weights of 2 lb., 3 lb., 4 lb. and 6 lb. to the square foot.

678. Galvanized Iron is thin rolled iron dipped into a bath of zinc, which gives it a bright and rust-resisting external surface. It is supplied in flat and corrugated sheets. The flat sheets are 6 ft. long in widths of 2 ft., 2 ft. 6 in. and 3 ft. The thickness of the iron is called the gauge. For building purposes it can be obtained from 16 gauge to 28 gauge; 22 gauge and 24 gauge being those most generally used. Corrugated galvanised iron is the name given to the sheets when formed into waved surfaces across the width. The corrugations stiffen the sheets. The width from the top of one corrugation to the top of the next is usually 3 in. The depth of the corrugation is ¾ in. The sheets when corrugated are 2 ft. 2½ in. wide and are from 6 ft. to 10 ft. in length. The gauges most generally used are 24 and 26. That most generally used is 24 gauge. Anything thinner than this should be avoided if possible.

678a. Terne Coated Iron is thin rolled iron coated with an alloy of tin and lead. It is available in corrugated sheets of the same size and gauge as corrugated galvanised iron sheets as well as flat sheets. It is not as good as galvanised iron, but is sometimes used as substitute for roof and wall coverings. It cannot be used on roofs used to drain water, or tanks, used for drinking purposes.

679. Zinc is prepared in sheets, 7 ft. x 2 ft. 8 in., 7 ft. x 3 ft., and 8 ft. x 3 ft., and the thickness is described by numbers, as follows: 7, 8, 9, 10, 11, 12, 14, 15, 16 and so on up to 26. 7 ft. x 3 ft. is the size usually used for building work.

680. Muntz metal is an alloy, consisting of 3 parts of copper and 2 of zinc. It is prepared in thicknesses weighing from 16 ounces to 20 ounces per square foot.

681. Copper is supplied in sheets 8 ft. x 4 ft., 8 ft. x 8 ft., 6 ft. x 4 ft., and 4 ft. x 4 ft., and in weight of from 16 ounces to 32 ounces per square foot. It is also procurable in a weight of 3 lbs. to the square foot.

682. Tin is supplied in ingots.

683. The Solder used by the plumber for jointing is divided into two classes, *i.e.*,

(a) Spelter.
(b) Soft Solder.

Spelter, for brazing brass, is composed of 2 parts of zinc and 1 of copper; and for brazing copper and iron, 2 parts of zinc and 3 parts of copper.

Soft Solder, for wiped joints, consists of 1 part of tin and 2 parts of lead.

Solder used for joints in galvanized iron consists of 1 part tin and 1 part lead.

684. Corrugated Galvanized Iron is used principally for roof covering, and occasionally for walls. The side joints of the sheet should have laps of two or one and a half corrugations, end laps or joints should be not less than 9 inches. It is secured to the battens by means of galvanized iron screws and washers. Two washers under the head of each screw should be used, one of galvanized iron and the other of lead. The lead washer is put under the galvanized iron washer to make a joint between the washer and the galvanized iron. If the lead washer alone were used, the process of screwing the screw into position would cause the lead washer to "cup," thus allowing the entry of water. The screws should be driven with a screwdriver, and not, as is sometimes done, with a hammer. If the latter be used the screws will have no hold and will be drawn out by the stress due to the heat of the sun. Screws should be put in in rows, not more than 36 in. apart, and not more than two corrugations should be missed in any row. This should be done, not only in the rows of screws at the end laps or joints, but also in the rows of screws across the centres of the sheets. The battens to which the galvanized iron is secured should be 3 in. x 1 in. oregon, or similar pine. Before fixing, the edges of the galvanized iron should be dressed to cling tightly at the side laps.

685. Zinc is sometimes used as a roof covering. For this

purpose it is unsuitable on account of its great liability to corrode. Especially is this the case in city atmospheres, where soot and aciduous solutions set up galvanic action with the zinc and eat it away. If zinc be used, soldered joints should be avoided. The joints are made with rolls in the same way as for lead, which will be described in the next article. As already noted the sheets are made 3 feet wide. This circumstance will regulate the spacing apart of the rolls.

686. **Lead** as a roof covering is generally used for very low pitches, indeed, in most cases, the use is for flat roofs. As in the case of zinc, only more necessarily so, the joints must not be soldered. The side joints are made on rolls nailed to the boarding on which the lead is to be laid. A section of a roll for lead jointing is shown at F, Fig. 157. These rolls should be spaced not more than 2 feet apart. End joints must be made as "drips," just as in the case of lead gutters. Nothing less in thickness than 6 lbs. lead should be used for roof covering. In the hot climate of this country lead covered flat roofs are rarely successful.

687. **Gutters.** In cold countries lead is almost invariably used for the lining of gutters. In Australia, however, where the heat from the sun is occasionally very great, a material like lead, which is very sensibly affected by heat, is most unsuitable for this purpose. Lead expands, and under the restricted conditions in gutters, and similar places, cracks occur, and consequently leakage results. It is much the better plan to use either the stoutest gauge of galvanized iron, or, if circumstances will permit, Muntz metal or copper or asbestos cement. In most cases it will be possible to use galvanized iron only, which, however, serves very well for the purpose.

688. **In the chapter on Roof Construction,** the forms of gutter between roofs, at the backs of chimneys and behind parapets, usually termed box gutters, were described (see Art. 445, *ante*, and Figs. 77, 79, and 84). The position of the galvanized iron, in these various gutters, is shown. It is here only necessary to describe the work particularly relating to the plumbers' trade. The galvanized iron should be not less than 24 gauge, and 22 gauge or even thicker will make very much better work. It must be noted that the flat galvanized sheet iron, used for the lining of these gutters, can be obtained only in sheets 6 feet long, so that joints in the length of the gutter will be needed, at least every 6 feet, less the amount of lap of joint. These joints should be formed with ample lap, well rivetted, and soldered on both lower and upper edges. An expansion joint or "drip" will be needed about every 23 feet.

The formation of the timber work for such a joint is shown in Fig. 84. If lead be used, the "drip" or expansion joint must be put in at least every 12 feet of length of gutter. It is a pretty safe rule to arrange for as much fall as possible in the length of the gutter, to provide for the rapid get-away of the water into the rain-water head. The fall must not be less than 1 in. in 10 feet. A lead or galvanized iron lined box or "cesspool" should be formed at the ends of gutters behind parapets. This should have its bottom much below the end of gutter, and also below the level of outlet from it. By this means any rubbish is caught in it and prevented from stopping up the outlet to the drain pipe. (See Art. 445, *ante*). A section of cesspool is shown in Fig. 84. R is the outlet from the side. An alternative is to make the outlet with a wire mesh top in the bottom as also shown by the sketch, Fig. 84. The outlet in the bottom is, however, not nearly so good. If the outlet in the bottom be necessary, then R should be provided as an overflow leading to the outside of building.

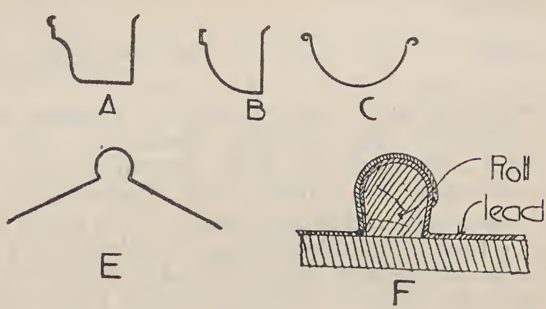


FIG. 157

Asbestos cement box gutters can be manufactured to order in any size and thickness required in lengths up to 10 ft. 6 in. with outlets, junction rain heads and external rain heads to any design. The joints are made with bitumen. These gutters are fitted in a similar way as for galvanized iron.

689. Eaves Gutters. These are generally formed of 24 gauge galvanized iron, rolled to a shape known as "ogee," but "quarter round," and other forms may be obtained. It is supplied in lengths of 6 feet, which require to be lapped, rivetted and well soldered. Eaves Gutters are shown at A, B, and C, Fig. 157. The gutter should be secured to the eaves with supporting brackets. These brackets are made out of 12-gauge galvanized iron hoop 1½ in. wide. They may be procured in thicker gauges, and even up to a quarter of an inch thick.

They are either short tailed, (as at A, Fig. 158), or long tailed, (as at B, Fig. 158). The long-tailed consists of the back of the bracket being long enough to go up for 3 or 4 inches on the foot of the rafter, to which it is secured by nailing. The short-tailed brackets only extend up as high as the back of the gutter, and are nailed on to the fascia or the end of the rafter. These may be easily drawn out, and is consequently not nearly so effective as the long-tailed kind. The brackets should be

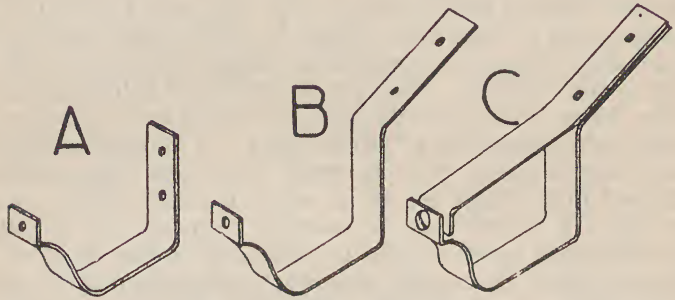


Fig. 158

spaced every 36 inches, that is, one to every second rafter, where the rafters are spaced at 18 inches centre to centre, or one on every rafter, where the rafters are spaced at 36 inches centre to centre. It is worthy of notice that the brackets are always to be spaced so as to coincide with the rafters as above described. The bracket is curved to fit the particular shape of gutter, and the gutter is secured to it by means of small galvanized iron bolts and nuts at the upper edge of the gutter. Eaves gutters should have sufficient fall to allow the water to flow away rapidly. Very often gutters are put up where this provision is not properly made, chiefly owing to the fact that there are not sufficient outlets from the gutter. It is impossible to give a long length of gutter sufficient fall, because of the "out of level" appearance that it gives to the eave of the roof. The best way is to provide outlets into the down pipes at frequent intervals, so that the falls are over short lengths of gutter. The width at the top of the gutter is either 4 or 5 inches, the latter being the width chiefly used. Of course greater widths may be used if necessary. All things considered, the 5 inch width of eaves gutter is the one most practicable; for it must be considered that if the gutter be too wide there is a tendency for it to lean over towards the front. This will especially be the case if the gutter were to have to hold a weight of snow. Galvanized iron over-straps (see sketch C, Fig. 158), secured to the front of the gutter, and passing

up the end of the rafter, are an excellent stiffening for the gutter, and would be worth adopting in all cases.

Asbestos cement eaves gutters can be made to order in any size required, the standard sizes being 4 in., 5 in., 6 in. and 8 in. and standard lengths 6 ft. to 8 ft. The joints are made in the same way as for the box gutters.

690. **Down Pipes** are the lengths of tubing which carry the water from the eave gutters to the drains. The water should not be led directly into the down pipe, but into a funnel at the top known as a "rain-water head." These rain-water heads (see H, Fig. 76) are ornamentally treated in accord with the design of the building. They are situated just below the eaves, and the water is led from the gutter to them by a curved piece of down pipe, known as a "lobster back." The rain-water head should have a piece of ½ in. mesh bird cage wire, soldered inside and near to the top of it, so as to strain off leaves and other rubbish which may be washed from the eaves gutter. An overflowing spout should be provided on the front of the rain-water head, in case of stoppage in the down pipe, otherwise the water flows over the back of it, as well as down the sides, thus causing dangerous dampness in the walls. The down pipes should be made of not less than 24-gauge galvanized iron, and since the lengths will occur at intervals of a little under 6 feet there will be many joints. The joints should be well soldered. The down pipes may be either circular of 3 in., 4 in., or 5 in. and upwards, in diameter, or they may be rectangular, either 4 in. x 2 in. or 4 in. x 3 in. and upwards in cross section. The rectangular pipes are the best. All bends should be curved, since right angles or "elbows" considerably reduce the water-carrying efficiency of the pipe. The curves may be either single or double. The double curve (shown at Fig. C 159), is known as "lobster back." It may be formed of sections of the down pipe soldered together. The down pipes are usually secured to the wall by spike hooks, but these are sometimes merely driven into the brick joint. If spike hooks are used they should be driven into cedar plugs properly driven into the brickwork joints (as shown at B, Fig. 159). A much better way is to use galvanized iron straps, about ¼ in. thick, and 2 or 3 inches wide, fitting round the pipe, with ends, through which screws are inserted into the cedar plugs in the wall. An example of one of these straps is shown at A, Fig. 159. Wall hooks, or straps for securing down pipes, should be spaced not more than 6 feet apart. Down pipes of cast iron about ⅜ in. thick and of varying diameter are also used. They are supplied in lengths of 6 feet.

Asbestos cement down pipes and rain-water heads can be

made to any size required and are frequently used instead of galvanized iron.

Down pipes should have elbows at the feet to turn the water off from the building. The down pipe should be connected directly with the storm-water drain.

691. Valleys. These are inclined gutters between the sloping surfaces of the intersecting roofs (see sketch A, Fig. 84). The best material to use for the lining of these valleys is 24 or 22 gauge galvanized iron, unless it be desired to make a better job, when muntz metal or copper would be used. The width is such as to allow 9 inches from each side of the centre line of the valley. The edge of the iron is turned to form a "bead"

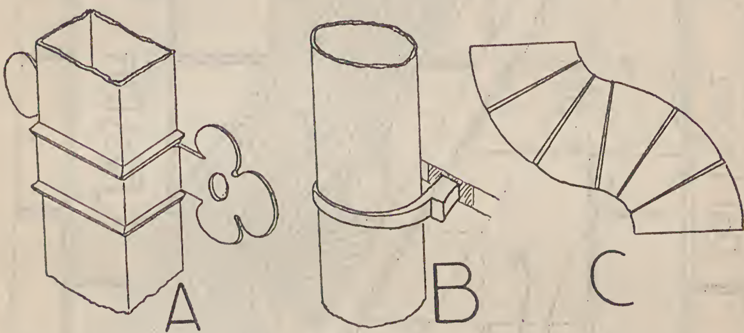


FIG. 159

at each edge of the valley. If this bead be not made, then a tilting fillet should be nailed on to the board and the iron turned down over it (see F, sketch Z, Fig. 84).

692. Ridges are covered with either lead or galvanized iron. Lead of 6 lb., for covering ridges, serves well enough, especially since it allows of the necessary dressing round the ends of the ridge in hip roofs. Sections of lead ridges on timber ridge rolls are shown by Fig. 76. Lead ridge capping is secured at intervals of about 6 ft., with $1\frac{1}{2}$ in. x $\frac{1}{8}$ in. iron straps, screwed to the top of the roll. Galvanized iron ridge capping is, however, very much used for ridges and certainly serves very well for the purpose. No ridge roll is required for this kind. A section of galvanized iron ridge capping is shown at ridges of roofs in Figs. 148 and 150, and at E, Fig. 157. This kind is secured with galvanized iron screws and lead washers at its lower edges. Galvanized iron ridge capping should be at least of 24 gauge, and formed out of galvanized iron, 18 in. wide. It is supplied in 6 ft. lengths.

693. Hips. Either 24 or 22 gauge galvanized iron or muntz metal will be found much the best for the purpose, since the lead, in expanding due to heat, will "creep" down the roll, and finally expose the hip. Screwing the lead will avail nothing, because the lead will drag on the screw, leaving an elongated

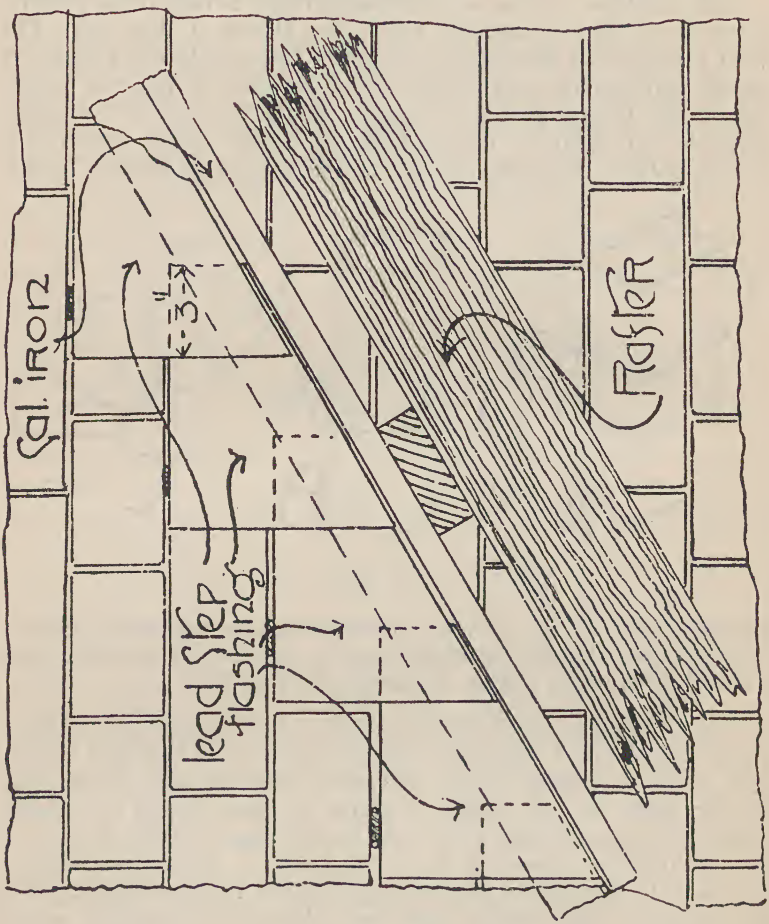


Fig. 160

hole due to the "creeping." The galvanised iron hip covering is the same as that used for ridge covering. As when used for the latter it should be secured with galvanised iron screws and lead washers at its outer edge.

694. Flashing. The sides of gutters against walls and all

joints of roof surfaces with walls, parapets, chimneys, etc., have to be protected by what is called "flashing."

Flashing may be either:—

(1) Stepped.
(2) Apron.

695. Stepped Flashing is formed as shown in sketch Fig. 160 with triangular shaped pieces. The upper level edges are inserted for at least 1 inch into the brick joint and fixed in position with lead wedges, which must be raked out for this to allow of such insertion. The joint is then painted with 3 and 1 cement. The steps overlap each other for at least 3 inches. If galvanised iron be the roof covering it is bent up against the wall for at least a height of 2 inches all the way up the intersection with the brickwork. The steps overlap this bent-up portion, and make a water-tight joint. If slates be the roof covering, they cannot be turned up like the galvanised iron. To make the joint, zinc angle pieces called "Soakers" are put in under the slates, and with one side against the wall. The lead steps overlap these soakers and so make a joint. A zinc soaker S is shown on the sketch, Fig. 86. In this case, however, the soakers are overlapped by weatherboards on the side of the Dormer, and hence no flashing is necessary. Stepped flashings are necessary with brickwork, since the joints of the latter are all horizontal. Obviously it would be impossible to cut a joint in the bricks parallel with the slope of the roof, so that what is called a "raking flashing" cannot be used. In masonry, however, this may be done, and a groove called a "raglet" is cut parallel with the roof and long pieces of flashing are put in. This is really a case of apron flashing.

696. Apron Flashing is shown at B, Fig. 79, AP Fig. 84, L Fig. 86, B. Fig. 87, and L. Fig. 90. As will be gathered from these sketches it is generally a horizontal flashing. The sketch B, Fig. 79, shows it in its most general form as the over flashing to protect the vertical side of the gutter lining. All kinds of flashing must be of lead. For ordinary purposes, 4 lbs. is used, but for good work 6 lbs. is necessary. Wherever it is necessary to fasten it in brick or stonework, such should be done with *cast* lead wedges driven well into the groove, at intervals of about 12 inches. The joint is then painted with 3 and 1 cement.

CHAPTER XVI

ROOF COVERINGS

697. Kinds of Roof Coverings. The different kinds in use are:—

(1) Slates.
(2) Tiles.
(3) Shingles.
(4) Galvanised Iron.
(5) Asbestos Cement.
(6) Muntz Metal.
(7) Zinc.
(8) Lead.
(9) Patent pliable coverings.

The ideal roof covering should be as nearly as possible non-heat conducting, durable, of good appearance, and fairly light in weight. It is practically impossible to get a material combining all these good points, and a compromise is inevitable.

698. Slates are very highly valued, chiefly on account of appearance, but are costly. They are, however, good heat conductors, and hence make hot roofs in hot, and cold ones in cool climates. This defect may, however, be overcome by putting a layer of felt or other non-conducting material under them. Another drawback is their liability to crack, especially in such conditions as an afternoon's shower of rain, following a very hot morning. While not being so heavy as tiles, they are yet in the class of heavy roof coverings. Slate is one of the metamorphic rocks; (see Art. 222, *ante.*). To be suitable for roofing purposes the rock must be so fissile as to be capable of being split into very thin pieces. The rock must also be durable when exposed. It is seldom that both thin lamination and durability are found in slate rock. The best quality obtainable are imported from the famous slate quarries of Wales. The well-known purple coloured slates from Bangor are the best quality. This kind is imported in large quantities. A blue slate of poor quality from America is also imported in very large quantities, and extensively used for buildings of an inferior character. These slates are full of small crystals of iron pyrites, which decompose and disintegrate the substance of the slate. The consequence is that the slate changes to a clayey colour and crumbles away.

A green coloured slate is also imported from America. This kind is a mean in quality between the blue American and Welsh slates.

699. Sizes of Slates. Slates are cut into various sizes. The sizes chiefly in use are given in table XLVII, together with number required per square, weight per square, and weight per square foot. The regular sizes are also distinguished by names. These names are but little used in this country.

The 20 in. x 10 in. size is, however, very often referred to by its name of "Countess." This particular size is a favourite and with some reason, for it is a mean between the very large and very small sizes, and the proportion of width to length is good.

TABLE XLVII

Giving Sizes of Slates, Weight per Square and Weight per Square Foot.

Sizes in Inches	Number Required per Square of 3in. Lap	Weight per Square in lbs.	Weight per Square Foot in lbs.
24 x 12	115	601	6·01
22 x 12	126	600	6·00
22 x 11	138	605·8	6·06
20 x 12	141	619	6·19
20 x 10	170	571·2	5·71
18 x 12	160	582·4	5·82
18 x 10	192	597·5	5·97
18 x 9	214	579·08	5·79

The bottom of the slate is called the "tail" and the top "head."

700. The sketches, Figs. 86 and 161, show the method of arranging and fixing the slates on the roof. A row of slates is called a course. As will be seen, the slates are arranged to break joint. The lap is the amount which any one slate extends over the slate next but one below it. The place of the lap is shown on the section in sketch, Fig. 161. The lap should be 4 inches. It is, however, very often made 3 inches. The distance between the line of tails of one course and that of the next is called the gauge. This is also marked on Fig. 161. The slates are secured with nails (of which there are two through every slate) to 2 in. x 1 in. pine battens spaced to suit the size and lap of slate. The best nails are those made of galvanised steel. Zinc and copper nails are also used occasionally. In the sketches the nails are shown put in at a line a little above the centre of the slate. Sometimes, however, the nails are put in near the head. This position gives a great leverage to

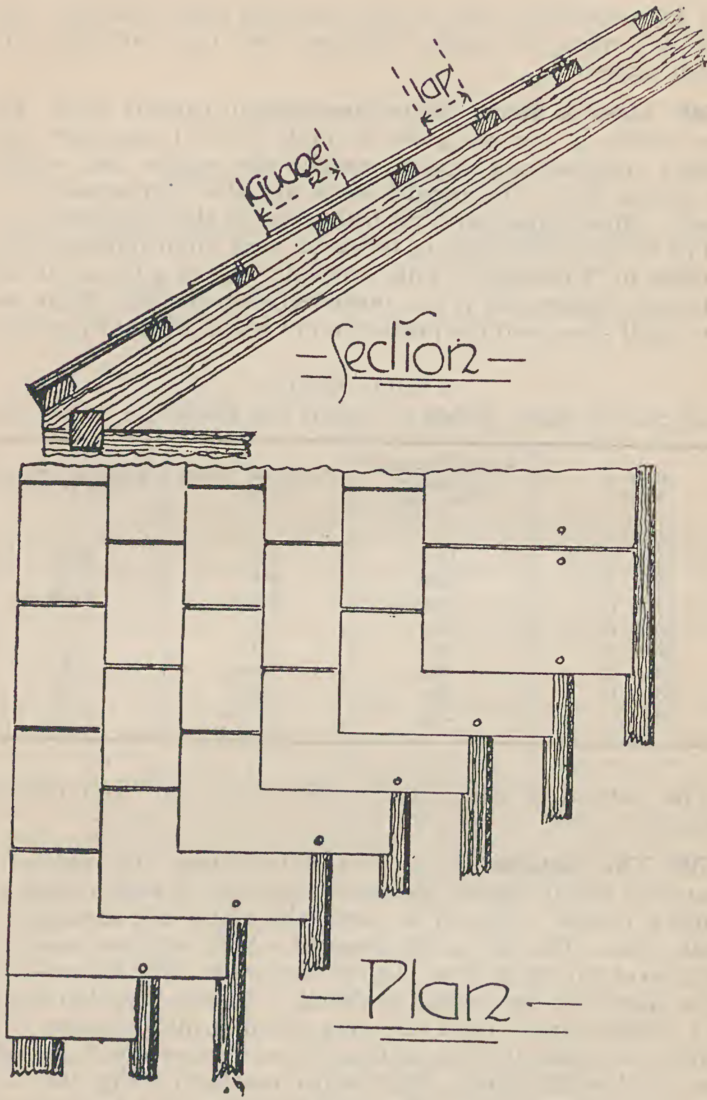


Fig. 161

the slate in windy weather, and allows them to get loose. The position of the nails as shown in the sketches is much the best. In very good construction the slates are nailed to boarding which covers the rafters (as shown in sketch, Fig. 86). A layer of felt, $\frac{1}{4}$ in. thick, is put on the boards before the slates

are nailed on. This makes an excellent roof. The felt may also be put over the battens, when the latter are used instead of boarding. When neither boarding nor felt is used the slates should be rendered on the underside, over all joints, and against the battens with hair mortar, similar to that described in the plastering for first coat work. A row of cut slates will be necessary at both eaves and ridge. The lines of cutting of the slates up valleys should be perfectly straight. The lower edges of all courses should also be straight, and all "perpends" should be well kept. The putting in of courses of slates with diamond or half-round tails is to be depreciated, not because any of the construction is affected, but rather on account of the fact that the plane surface which is a feature of a good slate roof is destroyed by these cut courses.

701. The hips of slate roofs are usually covered either with lead or galvanised iron capping. A very neat finish may, however, be made by mitreing the slates. If this is to be done the pitch of the roof must not be less than 45 degrees. For safety, it will be advisable to put "soakers" under the slates on the hip.

702. A very neat roof may be made if both hips and valleys are mitred. Soakers must of course be put in the valleys. The slates at the mitre should be secured with brass screws.

703. Terra Cotta Tiles. This kind of roof covering is heavy, but it is very much better as regards conduction than slate. Its appearance is also satisfactory in suburban and country architecture, where the complementary colour in the landscape compensates for what, in city architecture, remains a garish red.

The shapes of tile most used are:—

(1) French Pattern.
(2) Plain Tiles.
(3) Spanish Tiles.

704. The French Pattern Tile is about 16 in. x 9¾ in. x 7/16 in., and is shaped as to effectually cover at sides and ends of each tile, without more than what is practically one layer of tiles in the roof. They are also provided with a little projection on the under side, containing a hole through which copper wire may be passed and thence round the 2 in x 1 in. batten, thus making it possible to secure each tile. See sketch C, Fig. 161a. Unfortunately very often each tile is not so secured, and trouble results when high winds blow. A very good and secure roof surface may be obtained with these tiles, provided that each is wired with copper (not iron) wire to the battens. When

using these tiles a style of roof as simple as possible should be adopted, since they do not lend themselves readily to covering small gables, dormers, and so on, as they do not cut well for hips and valleys. They are best used for plain gable roofs with as few valleys as possible.

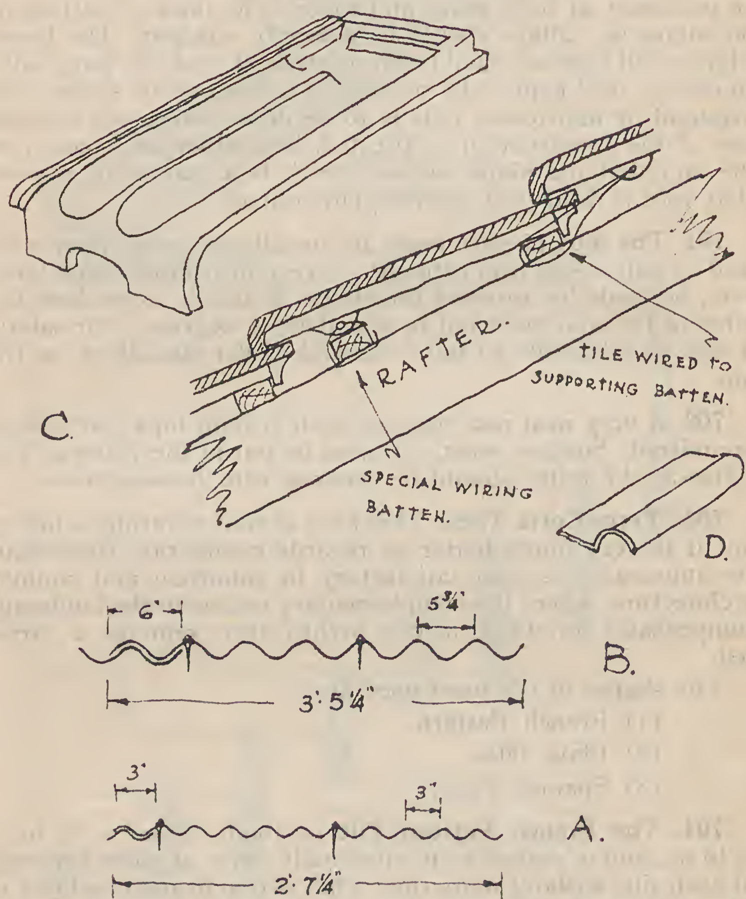


FIG. 161A

705. Plain Tiles are about 10½ in. x 6½ in. x ½ in. Usually they have a couple of small lugs on the underside near the top edge. They are hung by these lugs on the battens. They are secured by nails through holes just below the top edge. The arrangement of the tiles is similar to that of slating, the lap being about 2 in. These tiles should be rendered on the under

side with hair mortar. As will be seen by table XLVIII this kind of tiling makes a very heavy roof covering, but it also makes the best looking kind of tile roof. The partially vitrified tiles of a dark red colour are the best.

705a. A typical Spanish Roof Tile is illustrated at sketch D, Fig. 161a. In this example the tile is $14\frac{7}{8}$ ins. x $10\frac{1}{4}$ ins. and is fixed with wire as described in Art. 704 *ante* to 2 in. x 1 in. battens spaced at 12 in. centre to centre.

706. Tile Ridging. Ridge and Hip Capping of terra cotta is always used for finishing roofs covered with tiles. The capping may be either of half-round or triangular section. The lengths are fitted together in the same way as drain pipes, that is with spigot and collar joint. The capping should be bedded in cement mortar, stained red to match the tiles.

707. Shingles. This form of roof covering makes a cool roof in summer, and a warm one in winter, and looks really well. It is also a durable covering. A shingle roof has, however, one great drawback, and that is liability to fire. This great danger is sufficient to make it a question as to whether such a roof covering should be used at all.

Shingles may be divided into two classes:—

(1) American Redwood.
(2) Australian Hardwood.

708. American Redwood Shingles. These shingles are 16 in. long and of varying widths from 3 in. to 9 in. At the tail they are 5/16 in., and diminish to a feather edge at the head. They are arranged in the same way as slates, but the lap is usually 6 ins. They are nailed to pine battens with wire nails. The shingles should be dipped in boiled linseed oil, to which ochre or other pigment is added, to give a stain before being put on the roof. As a rule, however, only the tails are dipped in oil. Patent stains of wide range in colour and preservative of the timber are extensively used in America, and may be procured in this country. Redwood shingles weigh about 1.5 lbs. per sq. foot of roof covered.

709. Australian Shingles are split from Forest Oak. This timber makes an excellent shingle which does not need steeping in oil. As it weathers it takes a very pretty silver-grey appearance, which makes a most pleasing appearance as a roof covering. These shingles are about 12 in. x 6 in. and should be laid with a 3 in. lap. A square foot of covering of forest oak shingles weighs about 4.5 lbs.

710. The Metal Roof Coverings have been described under the head of plumbing (see Arts. 684 to 686 *ante*).

710a. Asbestos Cement Roofing Sheets are available in corrugated form. There are two types, one with standard corrugations as at A, Fig. 161a, and the other with larger corrugations as at B, Fig. 161a. The former is approximately 7/32 in. thick and 2 ft. 7½ in. wide and the latter is approximately ¼ in. thick and 3 ft. 5¼ in. wide. Stock lengths are 5 ft., 5 ft. 6 in., 6 ft., 6 ft. 6 in., 7 ft., 7 ft. 6 in., 8 ft., 8 ft. 6 in., 9 ft., 9 ft. 6 in. and 10 ft. The standard corrugated sheet has corrugations 1 in. deep, is 3 in. between corrugations, and is fixed with 3 in. side lap and 6 in. end lap. The large corrugated sheet has corrugations 1⅞ in. deep, is 5¾ in. between corrugations and is fixed with 5¾ in. side lap and 6 in. end lap. A pitch of 20° is recommended for this type of roof covering. Holes should be drilled in the sheets and not punched. The sheets can be fixed to either wood or steel purlins or battens which should be spaced at 36 in. centres for standard corrugated sheets, and up to 4 ft. for large corrugated sheets. Galvanised screws with galvanised iron washers and bituminous felt washers should be used for fixing to timber, and hook bolts or bolts, with galvanised and felt washers to steel. The screws or bolts should be dipped in plastic bitumen before fixing. Curved sheets as well as all necessary fittings such as ridge capping, sky lights, hips, and side flashings are available. Asbestos cement roofs are fairly economical, and they have been known to stand for 20 years. They are rustproof and consequently are proof against sea air.

711. Patent Pliable Roof Covering Materials. Many kinds of water-proof non-inflammable materials suitable for roof coverings, such as Malthoid, are now obtainable. They are usually felts impregnated with asphalt and supplied in rolls 72 ft. long and 3 ft. wide, covering 200 sq. feet of roof area, allowing for 2 in. laps. These roof coverings are made in different thicknesses and widths, and sold in rolls. For these coverings a foundation of boarding, an inch or more in thickness, must be laid on and nailed to the rafters and two or three layers of the material fixed to it. For concrete roofs the first layer is placed direct on to the concrete.

712. Weight of Roof Coverings. The table XLVIII gives the result of some experiments made some time ago to ascertain the relative percentage of absorption of tiles and slates. The table also shows the weight per square of these materials when thoroughly exposed to the rain. Table XLIX gives weight per square foot of different kinds of roof coverings.

TABLE XLVIII

Showing Absorption of Water by Different Varieties of Roofing Tiles and Slates.

Specimens thoroughly dried prior to immersion.
Time of immersion, 24 hours.

No. of Specimen	Description	Size	Percentage of Porosity	Weight per Square wet in lbs.	Remarks
1 2 3 4 5 6	Foreign Terra Cotta Corrugated Tiles.	16in. x 9¾in. x 7/16in.	18·21	751	Completely saturated at expiration of immersion. Light red colour.
7 8 9 10	Local Terra Cotta Corrugated Tiles, same pattern as Foreign Manufacture.	16in. x 9¾in. x ½in.	10·45	964	Completely saturated Light red colour.
11 12 13 14 15 16	English-made Tiles.	10½in. x 6⅜in. x ½in.	7·21	1,495	Hard close grained—partially vitrified Dark red colour.
17 18 19 20 21 22	English-made Tiles.	10¼in. x 6¾in. x 7/16in.	2·32	1,254	Very hard—vitrified—dark red or brown in colour. Section showed after immersion very little water penetration. Note: Brown coloured tiles showed smallest absorption.
23 24 25 26 27 28	Bangor Purple Slates.	20in. x 10in.	·89	580	Very close grained and compact. Slat completely dried in 4 minutes in a temperature of 65°.
29 30 31 32 33 34	Common American Slates.	20in. x 10in.	1·98	653	

TABLE XLIX

Showing Weights per Square Foot of Different Kinds of Roof Coverings.*

Kind of Covering	Weight in lbs. per Sq. Foot
Welsh Slate, 20in. x 10in., 3in. lap	5·8
American Blue Slate, 3in. lap	6·5
French Tiles	7·51
Australian Tiles, French pattern	9·64
English Plain Tiles, partially vitrified	14·95
Shingles, American Redwood	1·5
Shingles, Australian Oak	4·5
Galvanised Iron, Corrugated, 24 gauge	1·6
Lead—the weight per foot of the thickness used	5 to 6
Zinc—weight will depend on the gauge. A gauge very often used is No. 15, which weighs ..	1·31
The weight per foot of pliable roof covering will depend on the kind and thickness. A well-known kind, 3-ply in thickness, weighs ..	·49
Oregon Pine, 3in. x 1in. battens, for 20in. x 10in. slates	1·0
Oregon boarding, 1in. thick	2·83
Corrugated Fibro Cement—large corrugation ..	2·5

* The weights for the different roof coverings do not include nails, battens, or boarding.

CHAPTER XVII

PLASTERING

This subject may be divided into two classes, *i.e.*,—

(a) External work.

(b) Interior work.

713. External Plastering. This really resolves itself into either the covering of the wall or exterior of the building, with the rendering of cement mortar, called stucco, or else the dressing of all base courses, sills, mouldings, etc., of a building having the plain wall surfaces finished with O.K. or other bricks.

714. Materials for External Plastering. These are well washed sharp sand and Portland cement. Both of these materials have already been described in articles 47 to 59, and 64 to 67.

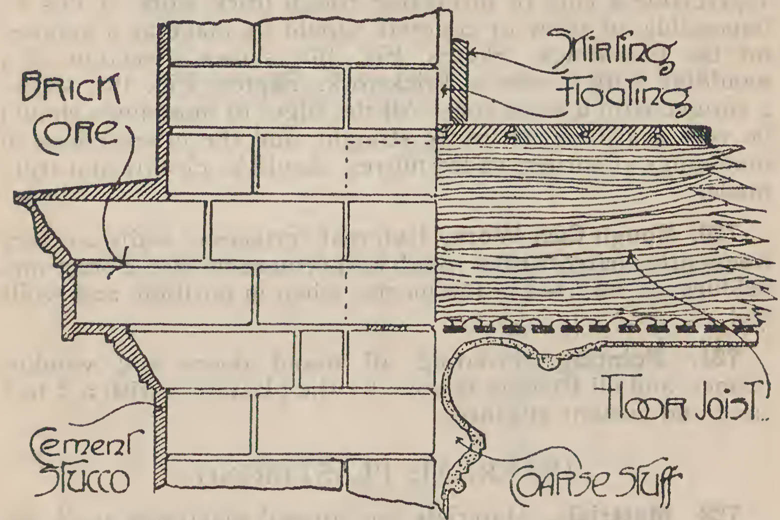


FIG. 162

715. The proportions of Sand and Cement for rendering. As a rule the proportion is 3 of sand to 1 of Portland cement. For all "arrises" of openings and other exposed positions the proportion should be at least 1 of Portland cement to 2 of sand.

In first-class work the whole of the stucco is carried out in 1 of Portland cement to 2 of sand. Generally the rendering is done in one coat, but sometimes it is put on in two coats, the last coat being about $\frac{1}{4}$ in. thick. Where there is only a single coat the average thickness is $\frac{3}{4}$ in.

716. All surfaces of the work should be finished quite smooth with a steel trowel; but on no account should the work be struck out in joints to imitate stone. In the first place the imitation is fraudulent, and in the second place this scratching of the cement surface generally means a crevice into which the weather penetrates.

717. Plasterers sometimes mix lime water with the cement rendering to make it work "fat." This practice is to be condemned, as lime and cement fail to make a satisfactory mixture.

718. Mouldings. The various finishes of windows and cornices are very frequently carried out in cement mortar, since this material lends itself very readily to decorations of this kind. (See sketches, Figs. 162 and 163).

719. When the projection of the mouldings is at all appreciable a core of projecting rough brick work, if this be impossible, of stone or concrete should be made as a support for the mouldings. Sketch, Fig. 162, shows a section of a moulding with a core of brickwork. Sketch, Fig. 163, shows a cornice with a stone core. All the edges of mouldings should be very sharp and perfectly straight, and the intersections of mouldings at corners called mitres, should be cleanly and truly made.

720. Rough Cast Work. External surfaces of walls are very frequently coated with a rough cast cement mortar. Sometimes pebbles are inserted in the mortar when in position, and while wet.

721. Pointing. Pointing all round doors and window frames, and all flashing is done by the plasterers with a 2 to 1 sand and cement mixture.

INTERNAL PLASTERING

722. Materials. Materials for internal plastering work are lime, cement, sisal or hemp, expanded metal, plaster, and Keen's cement. The lime should be fresh burnt stone or shell. The sand should be sharp and clean. Plaster, and Keen's cement have already been described in Articles 60, 61, and 62, *ante*.

723. Sisal or Hemp should be long, clean and free from grease.

724. Laths. These are supplied in two kinds.

(a) Split Hardwood.
(b) Sawn Pine.

725. Split Laths are of Australian hardwood, are 3 ft. long, and are supplied in bundles.

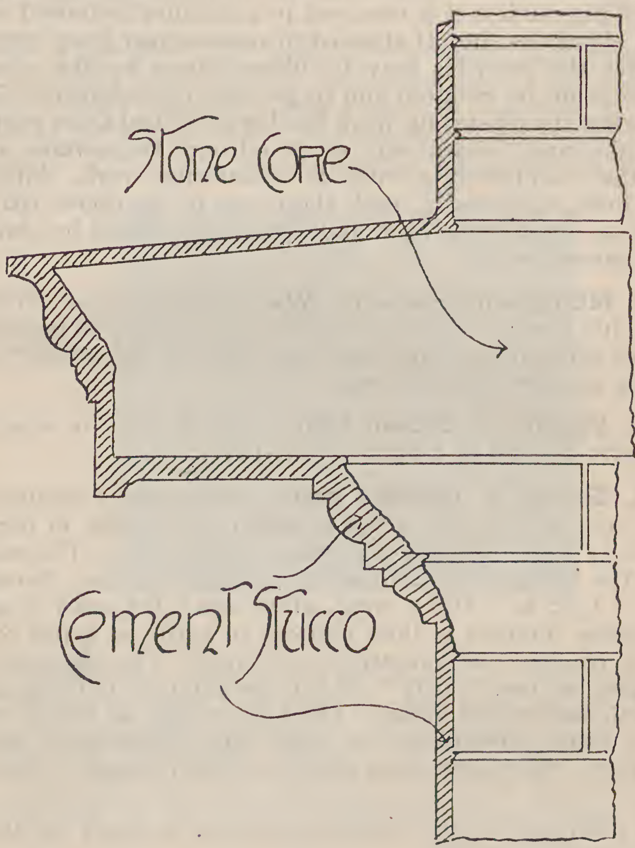


FIG. 163

726. Sawn Laths. These are $1\frac{1}{4}$ in. x $\frac{1}{4}$ in. and 4 ft. 6 in. long, and supplied in bundles. They are of oregon pine.

The use of these laths has, however, greatly diminished in recent years, and has been superseded by expanded metal.

727. Metal Lathing. Various kinds of metal lathing are used, and are excellent for the purpose. It is supplied in sheets and resembles chain wire except the surfaces are rough to form a key. See Fig. 164.

728. Lime. The lime for plasterer's use is slaked in boxes and then run through a fine sieve, into boxes, and allowed to cool. In this state it is called "putty." The residue from the sieve known as the "core" consists of particles of unslaked lime, and is likely to cause disaster to the plastering work of the building, unless it is removed to a distance or buried somewhere about the site. If allowed to remain near the plasterer's mixtures the particles may be blown about by the wind or thrown about by children and so get into the mixtures. Sometimes after the plastering work has been finished these particles will slake, and "blows" will occur all over the surface of the wall, thus completely ruining the plastering work. Although stone lime is generally used, there can be no doubt that the shell lime is much the best, and if possible, should be obtained for plastering work.

729. Mixtures for Plastering Work. First coat or "Pricking up." This consists of sand and lime-putty, in the proportion of $1\frac{1}{2}$ of sand to 1 of lime-putty and sisal in the proportion of one bag to every bag of lime.

730. Floating or Second Coat. This mixture is composed of 3 parts of sand to 1 part of lime-putty.

731. Setting or finishing coat is composed principally of lime; sand of very fine grain is added to the lime in the proportion of 3 or 4 buckets of sand to 1 bag of lime. The making up of the setting coat consists of running the lime through a sieve of 1/32 to 1/16 in. mesh, after which the sand is added. The whole mixture is then allowed to settle in a tub or box until it reaches the consistency of butter. The plasterer also calls this mixture "putty." When the mixture is being made, colour is sometimes added. The colour may be either red or yellow ochre, giving buff or pink tints. Blue-black gives a grey tint. The colour must also be sifted through a very fine sieve.

All mixtures for the plastering should be made up at least 14 days prior to using.

732. Lathing. If timber laths are used they are nailed with wire nails to the ceiling joists. They are spaced about $\frac{3}{8}$ in. apart, to give what is technically known as a "key." The end joints of the laths must be broken about every 2 ft. Sketch, Fig. 162, shows a section of some lathing with the plaster

forced between the laths and overlapping the tops of them to make a "key" or hold for the plaster. A great deal depends upon the plaster being well forced between the laths to make a good key. The various kinds of steel lathing, of which many are excellent for the purpose, are nailed on in sheets with wire nails to the ceiling joists. As a rule the plaster can be forced through to such an extent that the steel lathing is in the centre of the plaster, and this makes an excellent key. A photo reproduction of plaster forced through the steel lathing is shown by sketch, Fig. 164.

733. First Coat. This coat is put on laths or expanded metal for ceiling or stud walls. A very good job of first coat work, where timber laths are used, may be obtained by forcing "scrim," which is a kind of very loose texture bagging, into the first coat before it is dry. This makes a bonding throughout

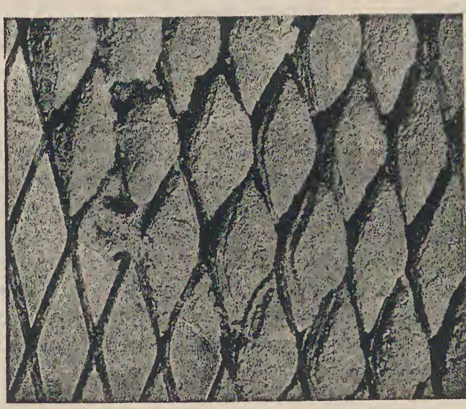


Fig. 164

the whole coat and improves its soundness. Immediately on putting the first coat up it is scratched with a piece of board cut with a number of points so as to make it rough all over and provide for a ready adhesion for the second coat.

If sand and cement be used on the laths or expanded metal, as described in Art. 734 the floating coat or second coat is omitted.

734. Second Coat. This mixture is the second coat on ceiling or stud walls, or the first coat for brick or stone wall surfaces It is known as the "Floating Coat." It should not be put on the pricking up coat until the latter is quite dry. The floating or second coat is made perfectly even and fair on all wall and ceiling surfaces. On the walls it is made to come flush with

the plugs for skirting and architraves, already put in by the joiner and sawn off to prepared lines of evenness. Bands of floating, about 4 or 6 ins. wide are put along the bottoms and tops of the walls, and at intervals of 3 or 4 ft. between. These are called "screeds," and are made straight and fair with long pieces of wood called straight edges. The floating is then put in between these screeds and evened up fair with them by straight edges, or by a long two-handled float called a "Darby Float."

In better class work and where strength is required a 3 and 1 sand and cement mixture is used as a floating coat.

735. Setting Coat. This consists of the mixture already described, but with the addition of some plaster of Paris added to it just before being put on the wall. The plaster is added in the proportions of about 12 lbs. of plaster to each 144 sq. ft. of setting surface.

The setting coat is only about 1/16 in. thick, and is put on with a steel trowel and worked up to a high degree of smoothness and polish. Very frequently for wall surfaces the setting has added to it one of the ochres or blue-black to give a tint. Unfortunately it is a very difficult matter to get an even tint all over the wall surface in this way. Especially is the difficulty great when the attempt is made to get a grey colour. Necessarily the upper part of the wall has to be set first from the scaffold, then the lower part is done. The joint between these two settings is very difficult to accomplish satisfactorily. The best way is to set the walls as well as the ceiling white, and then at some future time to colour with kalsomine or to paint to the required tints.

736. Internal Mouldings. Such as cornices, imposts, architraves, angle mouldings, and so on, are run in lime-putty and plaster, in the proportion of 1 to 1. The plaster is added just before using the mixture. The moulding is run on a core of floating or "coarse stuff." To support cornices of large projections or coves of ceilings, wooden brackets (see sketch, Fig. 165) are put up at intervals, and laths attached thereto. The cornice or cove is then run on this framing. Sketch, Fig. 166, shows section of an angle ovolo for salient angles. Generally cornice mouldings are constructed of fibrous plaster.

737. Keen's Cement Setting. In first-class work the internal plastering of the wall surface is done with Keen's cement. In this case the floating coat consists of Portland cement and sand in the proportion of 1 to 2, or 1 to 3. Keen's cement is then put on this as a setting coat, and allows of the production

of a very highly polished and partly translucent surface. See Art. 61, *ante*.

738. Plaster Ornaments. Ornamental work such as enrichments in cornices and coves and caps of pilasters and columns are first of all modelled in clay, from which a mould in gelatine is obtained. In this gelatine mould is cast in plaster of Paris

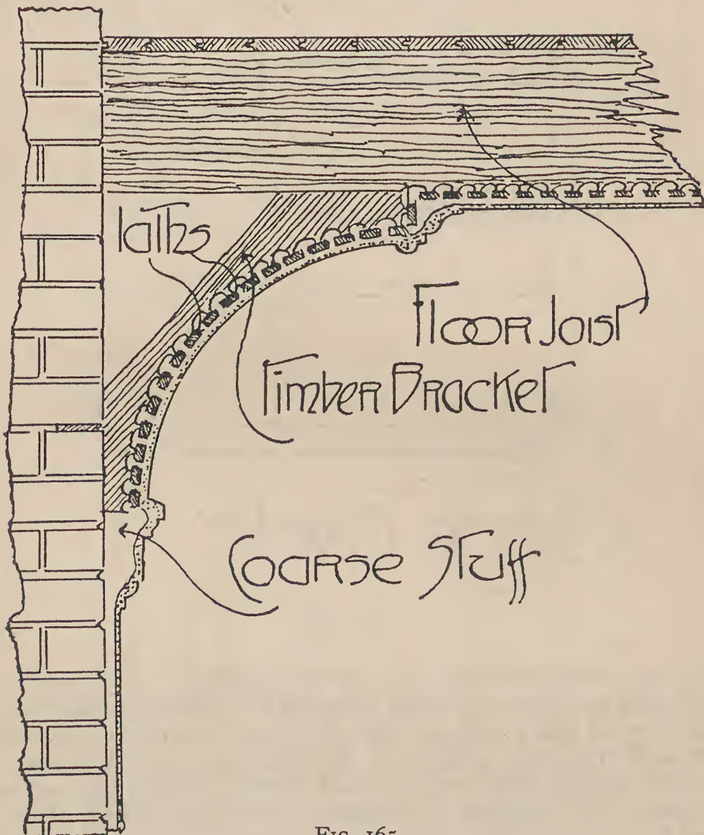


FIG. 165

a replica of the original clay model. The plaster enrichment is held in position in its place in the building by copper wire or on copper spikes and plaster of Paris, or if it be light in weight, by the plaster of Paris alone. It is, however, only in first-class work that ornament is especially modelled and cast as just described. As a rule these ornaments are kept in stock

by the modellers, and are selected by the architect or builder from the stock in hand.

739. Fibrous Plaster. This is manufactured with plaster of Paris reinforced with sisal hemp. It is conveyed to the building in sheets, and is screwed or nailed to the joists or to brandering battens. The method of this preparation enables it to be made with the exposed surface in any particular design. Cornices and other mouldings are also prepared in lengths

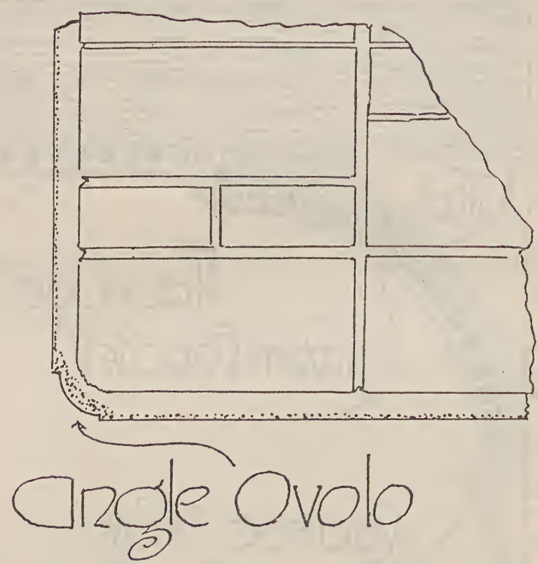


Fig. 166

ready for fixing into position in the building. The joints of sheets and cornices are either covered with beads or mouldings or else made good with plaster of Paris. The main advantage of this system for ceilings is its soundness, so that the old troubles arising from cracked and falling ceilings are entirely obviated. The battens, sometimes called brandering battens, should be 2 in. x 1 in. oregon and should be spaced at about 12 in. centre to centre. The sheets are usually either $\frac{1}{4}$ in. or $\frac{3}{8}$ in. thick, but can be obtained in thicker sheets, and vary in stock sizes from 6 ft. x 3 ft. to 10 ft. x 5 ft.

Internal mouldings such as indicated in Figs. 165 and 166 can be obtained in fibrous plaster.

Fibrous plaster sheets are also used as a lining to rooms with stud walls, where the sheets are fixed either direct to the

studs or to battens nailed to the studs, and the joints are covered with wood cover strips or set with plaster of Paris.

739a. **Wallboards.** The internal face of stud walls and ceilings are often finished with wallboards such as Celotex, Tentest, Caneite and Masonite. Most of these boards have insulating properties and are useful as a soundproofing measure on ceilings. They are sometimes nailed to battens, but generally direct to the studs. The sheets are generally butted together and finished with a V joint.

CHAPTER XVIII

PAINTING

740. Portions of buildings made of timber, iron, or steel when exposed to the weather are rapidly affected and should be protected with paint to prevent decay. Wall surfaces either of stone, brick, or when rendered with cement are sometimes painted to prevent the passage of rain water through them. Internal wall surfaces and other internal parts of buildings are painted, kalsomined, or otherwise finished. This is generally done for the sake of decorative effect.

741. The materials used to make Paint may be classified as follows:—

(a) Bases.

(b) Vehicles.

(c) Solvents.

(d) Driers.

(e) Pigments or "Stainers."

742. (a) The Base is the actual covering material, and consequently is a very important constituent of the paint. The base most commonly used and under most circumstances absolutely the best is White Lead. This is a carbonate of lead produced by corrosion of the metal when exposed to the fumes of acetic acid. In its original form it is a white powder, but as supplied to the painter is ground in linseed oil to a stiff paste. It should be used pure, but is often adulterated with such substances as sulphate of baryta, sulphate of lead, sulphate of lime, whitening, and chalk. Pure white lead is soluble in nitric acid. White lead improves with age, provided that it be protected from the action of the air.

743. Red Lead is also a useful base, especially for painting iron. It is a bright red powder produced by heating massicot to a high temperature, when oxygen is absorbed, forming an oxide of lead or "red lead."

744. Oxide of Zinc. This is a useful base, especially where a permanent white is required. It is, however, not nearly so good in its covering power as white lead.

745. Oxide of Iron, produced from brown Haematite ore, is also a useful base, particularly for painting iron work.

745a. Titanium Oxide. This is a relatively new base where white is desired. It is an element found in nature in minerals such as Ilemite and Titanite and when isolated is a grey crystalling powder.

746. (b) The Vehicle is the oil which is mixed with the base to allow of the latter being spread or brushed thinly over the surface to be painted.

747. Linseed Oil is the most important of oils suitable for the above purpose. The oil is produced by pressure from flax seed. It is used either *raw* or *boiled*.

748. Raw Linseed Oil should be perfectly transparent, and of a pale amber colour, rather sweet in taste. A film of this oil on glass should dry in from 2 to 3 days.

749. Boiled Linseed Oil is produced by mixing driers with raw oil and heating the mixture to a high temperature. It dries very much quicker than raw oil. A film on glass should dry in 24 hours. Can either be pale boiled or dark boiled. Boiled oil should not be used on timber.

750. Worthless substitutes for linseed oils, such as animal, fish, and mineral oils are frequently used by unscrupulous tradesmen with the worst results. Oil from the seed of the poppy, known as *Poppy Oil,* and *Nut Oil* from walnuts, while not being so good as linseed, may yet be used with success.

751. (c) Solvent. This is an oil mixed with the paint to make it work easily. The solvent generally used is Spirits of Turpentine, obtained by distilling turpentine from pine trees. It is a colourless volatile oil with a very pungent smell. Good turps should give a hard varnish film on glass in 24 hours.

752. (d) Driers are added to the paint to make it dry rapidly. Litharge, an oxide of lead, is a good drier, and one that is very much used. Red Lead is often used as a drier, but of course can only be so used where its colour will not interfere with that of the particular tint of paint wanted. Terebine is a very rapid drier. There are also different kinds of *patent driers* to be obtained, many of which give very good results.

753. (e) Pigments or "Stainers" are not essential to the

paint as a covering and protective medium, but are used to obtain the necessary colour. There are very many different pigments used. The commonest are raw umber, raw sienna, burnt umber, burnt sienna, yellow ochre, lamp black, prussian blue, indigo, chrome yellow, red lead, Indian red, light red, venetian red, chrome green, and so on. Some of the pigments such as carmine, ultramarine and cobalt are expensive, and only used in high-class decorative work.

754. Proportions of Ingredients of Paint. It is not easy to give definite information as to the best proportions of the different materials to make paint, since there must be a variety of climatic conditions, which will have an effect, and there are so many different kinds of timber, and other materials to be painted. The Table L gives proportions for making paint suitable for painting pine and other soft timber. The materials should be well mixed and then strained. The pigment or "stainers" is mixed separately, strained and added to the paint.

754a. Ready Mixed Paints. Ready mixed paints ready for use, which are made of first-class materials are available and may be used for good class work. It is possible to obtain from manufacturers of repute almost any base ground in oil, the purity being guaranteed. No thinner or other such material should be added to these paints unless the manufacturer be consulted. Such paints can be obtained with glossy or flat finishes.

754b. Aluminium Paint. Consists of aluminium powder suspended in a medium, such as spirit varnish or oil varnish. Such paint has heat resisting properties and is useful for painting surfaces of flues, hot water pipes, etc.

754c. Enamel Paints, as the name implies, such are ready mixed paints which when applied to surfaces give a glossy finish, which will withstand severe treatment as in kitchens or bathrooms. This kind of paint supersedes the old method of varnishing the painted surfaces to get a glossy finish.

754d. Lacquers are synthetic paints giving a highly glazed finish, are quick drying and are sometimes used in preference to enamels. Lacquer, sometimes called cellulose, is produced from nitro-cotton. The finishes are entirely different from paints and only the pigments are common to both. It leaves a hard finish which can be washed even with hot water, and resists extremes of hot and cold. It can be applied either by a spray gun or by a brush. Only special thinners as supplied by the manufacturers should be used.

TABLE L

Showing Proportions of Ingredients to Make Different Coats of Paint.

Coats	Red Lead, Lbs.	White Lead, Lbs.	Raw Oil, Pints	Boiled Oil, Pints	Turps, Pints	Driers, Ozs.	Remarks
External—							
Priming	1	9	1	1	—	1	Many painters use much more red and less white lead in the priming coat than is noted here.
Second .	—	7	1	1	$\frac{1}{4}$	$\frac{3}{4}$	
Third ..	—	7	1	1	$\frac{1}{4}$	$\frac{3}{4}$	
Fourth .	—	7	$1\frac{1}{2}$	1	—	$\frac{3}{4}$	
Internal—							
Priming	$\frac{1}{4}$	8	3	—	—	2	
Second .	—	7	$1\frac{3}{4}$	—	$\frac{3}{4}$	2	
Third ..	—	6	$1\frac{1}{4}$	—	$\frac{3}{4}$	2	
Fourth .	—	6	$1\frac{1}{4}$	—	$\frac{3}{4}$	2	
Flatting—	—	$4\frac{1}{2}$	—	—	$1\frac{3}{4}$	2	The flatting is put on as a fifth coat to those given for internal work, but the turps is left out of third and fourth coats and more raw oil used instead.

755. Preparation for Painting. All surfaces to be painted must be well cleaned. Timber surfaces should be glass-papered, and all screw and nail heads driven or punched below the surface. All knots should be covered with "knotting," which consists of red lead ground in water and mixed with strong glue size. Patent knotting may also be used for the purpose. The knots are so treated to prevent them from either exuding gum, etc., or from absorbing paint. When the priming coat is dry, all nail holes, splits, cracks, and other crevices or defects in the surface must be stopped with putty, which consists of "whiting" reduced to a very fine powder and mixed to a stiff paste with raw linseed oil. Whiting is white chalk reduced to powder. Timber must be thoroughly seasoned before being painted. Surfaces which have been previously painted should have all the old paint removed by scraping or burning, and rubbing down with pumice stone. As a rule, however, unless the old paint is very thick and rough, the surfaces are only washed with a strong solution of soda, and made smooth with pumice stone.

756. The different coats of paint are laid on evenly, and each must be quite dry before another one is put on. In first-class work each coat is glass-papered smooth, prior to the next

coat being applied. Each coat is stained to approach a little more nearly the colour of the final coat. A last coat of paint consisting of white lead, turps, driers, and "stainers," and called "flatting," is put on as a fifth coat for internal work, where an even dead or flat colour is desired. When well done, a flatted surface is a very beautiful finish for internal work.

757. Iron Work. Should be painted with, at least one coat before being exposed to the weather. If rust be allowed to take place it is practically impossible to prevent its continuance under the paint as time goes on. The paints made with oxide of iron or zinc are best for ironwork, but must not be used with other paints lest galvanic action be set up, and cause a rapid decay. Two coats will be quite sufficient for iron or steel work.

758. Size is made by melting good glue in water, and adding water until the proportion of 1 lb. glue to 1 gallon of water is reached.

759. Varnish is a preparation of resin in solution with oil, turpentine or alcohol, and is used to make a hard, transparent glossy film over paint. It is also used to coat unpainted timber surfaces, in which case it greatly enhances the natural beauty of the timber, especially if the timber has a good colour and grain.

760. Kinds of Varnishes. The principal kinds are:—

(1) Oil varnish.
(2) Turpentine varnish.
(3) Spirit varnish.

761. Oil Varnish is made by dissolving gum, such as *amber,* or *copal* in oil. It should dry in 24 hours.

762. Turpentine Varnish is made by dissolving *common resin, mastic,* or *dammar* in turpentine. This kind is not nearly so good as the oil varnish, though it dries much quicker. Turpentine varnish should be quite dry in eight hours.

763. Spirit Varnish is made by dissolving soft gum like *lac* or *sandarach* in spirits of wine. The varnish will dry in 2 or 3 hours.

764. Varnish may be put on painted work with much success, for it greatly adds to the appearance and increases the durability.

765. Wood Work should be coated with size before being varnished. Such beautiful timber as cedar, blackwood, and

others of the figured class need nothing but proper preparation for the varnish to bring the colour and figuring forth. Some of the plainer timbers are often stained with preparations of burnt sienna, vandyke brown, logwood, potash, etc., to produce certain colours, and enhance the natural grain. The wood must be quite dry. It is first stained, then coated with size, and finally coated with one or more coats of varnish.

766. Graining. Skilled painters are able to make very good imitations of the grain and figuring of high-class timbers. This is called *graining*. The timber is first coated with three or four coats of ordinary paint. The last of these coats is approximate in colour to that of the timber to be imitated. A coat consisting of burnt sienna, umber or vandyke brown, etc., in water, or beer, or oil, is then laid on and figured by means of a metal or india rubber comb and by dexterous touches of a sponge to represent the grain and markings of cedar, oak, maple, or others of the expensive timbers. When this graining coat is dry it is coated with two coats of varnish. *Over-graining* consists of laying a thin coat of the graining colour in shades over the first coat of graining. It gives a depth to the graining that is a very good imitation of the beautiful natural shades of some of the best timbers.

767. Marbling. Just as with the graining the skilled painter succeeds in making excellent imitation of marble. The surface is first coated with three or four coats of good paint. The shades and veins of the marble are then painted and marked in. The markings and veins are, however, put in with oil paint. The final finish is made with a couple of coats of varnish. While admitting that great skill is often shown by the painter in imitating the natural beauties of timber and marble, it is true that there is little to recommend the practice of the art, because make-belief, either in building or decoration, is reprehensible.

768. Painting Wall Surfaces. Internal and external wall surfaces are very frequently painted, the former for appearance, and the latter usually to keep them dry against the weather. In all cases the walls must be perfectly dry. No success will be attained in any case when an attempt is made to paint a damp wall surface. Neither is it possible to get paint to stay on new plaster or cement stucco or newly built brickwork. In such cases the lime or cement will kill the paint. Plaster and cement stucco or brick walls should be allowed to stand for 12 or 18 months before being painted. For internal plaster wall surfaces, the last coat should be "flatted." At least four coats should be put on all external wall surfaces. All

holes and cracks in the wall surface should be well stopped with putty, prior to putting on the second coat.

769. Colouring Wall Surfaces. External wall surfaces are frequently coated with lime and fat, as a protection against the inroad of rain. The fat must be put in the lime while the latter is hot. Colour is added to give the required tint.

770. Kalsomining and Distempering. Excellent results may be obtained by colouring the internal wall surfaces with kalsomine, which is supplied in a great variety of tints, and gives a very artistic "flat" surface effect. Kalsomine is sold in powder made up in packets, and only needs mixing with water. A very good distemper may be made as follows: To 7 lbs. of whiting add "stainers" to give the required tint. This is to be mixed with ½ lb. of fish glue, which must be previously melted, and diluted with water. The mixture is then to be strained through a piece of cheese cloth, after which it is ready for putting on the wall. This is to be prepared by being well cleaned and brushed down and coated with a varnish made up of equal parts of resin, varnish, and benzine. Very great difficulties arise at times with damp spots on walls, since, as above noted, it is impossible to paint or even kalsomine over them. The only safe way is to wait until the dampness dries out. The drying may be accelerated by covering the damp place with successive washes of sulphuric acid, which will rapidly absorb the moisture.

770a. Spreading Capacity of Paints. The following table will be found useful when estimating the amount of paint required for certain work.

TABLE LI

White Lead, 1 cwt. mixed into paint covers	500 - 750 sq. yds.
Zinc Oxdie „ „ „ „ „	700 - 1000 „ „
Red Lead „ „ „ „ „	560 - 590 „ „
Ready Mixed Paint	
1st coat on timber .... 1 gall. covers	50 - 55 sq. yds.
2nd „ „ „ .... „ „	60 - 65 „ „
3rd „ „ „ .... „ „	75 - 85 „ „
Water Paint	
On Plaster .... 1 gall. covers	30 - 35 sq. yds.

770b. French Polishing is the name given to a hard transparent film applied to timber, to preserve it and also to bring

its natural beauty into prominence. The finish is very durable, and was invented by a Frenchman. The following is an excellent recipe:—

12 ozs. of Orange Shellac.
1 oz. of Benzoin.
1 oz. of Sandarach.
½ gallon of Methylated Spirits.

Before attempting to French polish a surface it must be thoroughly clean and smooth. A rubber is used to apply the polish and consists of a centre of wadding covered with soft cotton or linen. To charge the rubber the covering must be removed and the centre is dipped into the polish.

Before the polish is applied the surface must be "filled in." Such is carried out by rubbing Russian tallow and plaster of Paris, or plaster of Paris and methylated spirits into the pores of the timber, and when dry the surface is sandpapered smooth. After the surface has been "filled in" it is ready to receive the polish. The rubber should be charged with polish and just before being used should have a small amount of linseed oil applied to the covering. The rubber should first be passed a few times gently over the surface in the direction of the grain. The surface should then be rubbed across the grain in a series of circular movements which should all be one way and in full and free sweeping strokes. This operation is continued until the surface assumes a satisfactory appearance. It is then left for 12 hours, after which the surface is lightly rubbed down with No. 0 sandpaper. The surface is given further applications of polish until sufficient body is obtained, when the "spiriting off" is commenced. The "spiriting off" is carried out using a rubber charged with methylated spirits.

770c. Lacquering. In recent years lacquering, which gives a clean transparent film to the surface has superseded French polishing. It is applied by a spray gun and forms a very durable surface not affected by severe temperatures. Lacquer, sometimes called cellulose, is made from nitro-cotton which is obtained by treating materials such as wood pulp, cotton linters, etc., with a mixture of nitric acid and sulphuric acid. The product is dissolved in solvents such as acetone, or amyl-acetate, and plasticisers such as castor oil or camphor are added.

770d. Paperhanging. Wallpapers are 12 yds. long by 21 ins. wide, and many various designs and colours can be obtained. The plaster walls should be perfectly dry and should be coated with size before the paper is applied. In first class work lining paper is put on under the wall paper. The paper is put

on with ordinary flour paste and the side joints can either be lapped or butt jointed, the latter being better. If walls are to be repapered the existing paper should be stripped from the surfaces.

GLAZING

771. Shop windows and light openings of public buildings are glazed with plate glass. This is a high quality of glass, rolled into plates and polished to nearly true plane surfaces. It is supplied in thicknesses of $\frac{1}{8}$ in., 3/16 in., $\frac{1}{4}$ in., $\frac{1}{2}$ in., $\frac{5}{8}$ in., 1 in., and $1\frac{1}{8}$ in. That almost universally used for windows is $\frac{1}{4}$ in. thick. This thickness may be obtained in sheets 196 in. x 136 in. It is held in place in the sashes with beads secured with screws. For shop windows the movable bead should be at the outside edge of the sash (see Art. 582, *ante*, and Fig. 109). Plate glass does not distort objects seen through it and while absolutely indispensable for shop windows, is always worth its cost for private houses. Plate glass is supplied in two qualities, namely, ordinary plate, and plate for mirrors. The ordinary plate is quite good enough for windows. Plate glass should never be bent for shop windows.

772. Sheet Glass is the common glass, generally used for windows of dwelling houses. It has uneven surfaces, and very often distorts the objects seen through it. It is described by the weight in ozs. per square foot. The weights are, 16 ozs., 21 ozs., 26 ozs., and 32 ozs. Sixteen oz. glass may be obtained in sheets 54 in. x 36 in.; 21 oz. in sheets 62 in. x 48 in.; 26 oz. in sheets 62 in. x 48 in.; and 32 oz. in sheets 66 in. x 44 in. Sheet glass is held in the sashes with putty and small sprigs when exposed to the weather. A thin layer of putty is put at the back of the rebate, then the glass is put in and sprigged. Finally an outer layer of putty is filled in and levelled off.

773. Mill Rolled Glass is a semi-transparent glass about $\frac{1}{4}$ in. thick, having one face smooth, and the other formed with narrow parallel grooves or corrugations. It is much used for windows of factory and store buildings. It may be obtained with embedded wire netting of about one inch mesh. This wired glass is a most excellent glazing for skylights, since there is no danger of falling pieces. It is also very efficient as a temporary bar to the egress and ingress of fire since it does not collapse like ordinary glass in the early stages of a fire.

774. Figured Rolled Glass. This kind includes a great variety of pattern glass, about $\frac{1}{8}$ in. thick. One face is smooth

and the other covered with a pattern. It is generally coloured in light tints. "Japanese," "Muranese," "Mallocene," and "Flannel Flower," are examples of this class. There are many places where it may be used to advantage, but it is quite unsuitable for windows or casements of rooms, since not only does it prevent a view through the windows, but it sheds a colour over the whole of the interior of the room with a most distressing effect. Some of this pattern of glass is colourless, and apart from the defect of semi-transparency is not objectionable for windows of rooms.

775. A Class of Rolled Glass similar to the above, but instead of the pattern it has one face wavy or roughened, so as to have somewhat of a crystalline appearance. "G," white, "Arctic," and "Flemish" are examples of this class.

776. Special forms of Rolled Colourless Glass, such as "Maximum light" are made to give a very brilliant lighting effect for dark rooms, such as those in basements or in other bad positions in the building.

777. Enamelled Glass. This is a thin glass having a pattern in ground glass fluxed into it. It is not used very much now.

778. Embossed Glass. This is a polished plate glass ¼ in. thick, with a design embossed in it. The embossing is done by first stencilling the pattern in Brunswick black. The surface is then subjected to the action of fluoric acid, which attacks and makes a ground glass surface on the unprotected parts. Embossing is done to suit the particular size as the occasion demands.

779. Lead Light Glazing. This consists of small pieces of glass held together with narrow lead bars with a cross section like the letter H. The glass is held in the groove on each edge of the bar. The glass is cut to various shapes, and the bars are bent to suit these shapes. This kind of glazing is carried out with the most beautiful effect for church windows, in which glass specially made for the purpose is used. For ordinary buildings the lead bars are shaped to geometrical and other patterns, and filled with different tints of the wavy or figured rolled glass described in Art. 774, *ante*. For certain places in the building, such as stair windows, hall doors, etc., this kind of glazing is very effective. A kind called "cathedral glass," which is a tinted wavy glass, is much used. The lead light glazing should be stiffened with metal bars placed across it at intervals.

780. Glazing Bars. Bars of skylights, if of timber, are too

slender to last well, and it is difficult to keep them water-tight. Metal glazing bars, of which there are different kinds procurable, are much superior. They are of steel, fitted with rebates to hold the glass and covering strips of lead. They are of small cross section, and consequently very light, and are easily fixed in the sash of the skylight.

781. Pavement Lights. These are prisms of glass let into iron frames which are placed level with footpath, to admit to and disperse light in basements. (See PR, Fig. 110.)

782. Structural Glass is translucent glass from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. thick, available in many colours and is often used as a facing to shop fronts and even large buildings. It is fixed with dowels and cramps against mastic putty dabs.

783. Glass Bricks in size about 9 in. x 6 in. are available and are used in openings where light only is required. They are set in cement mortar and the joints are pointed with a mastic putty. Reinforcing strips of hoop iron or some such material should be put in at every fifth course.

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

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WILLIAM BROOKS & CO., LIMITED, 99 PITT STREET, SYDNEY

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